INNOVATIVE CLEAN COAL TEClINOLOGY (ICCT)
500 MW DEMONSTRATION OF ADVANCED
WALL-FIRED COMBUSTION TECHNIQUES
FOR THE REDUCTION OF NITROGEN OXIDE (NOx)
EMISSIONS FROM COAL-FIRED BOILERS
Phase 3B LNB Plus AOFA Tests
Topical Report
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ACFM	Actual Cubic Feet per Minute
AOFA	Advanced Overfire Air
ASME	American Scciety Mechanical Engineers
APH	Air Preheater
Btu	British Thermal Unit
CAAA	Clean Air Act Amendment
CTTII	Clean Coal Technology II
CEMS	Continuous Emissions Monitoring System
CF/SF	Controlled Flow - Split Flame
DAS	Data Acquisition System
DOE	Department of Energy
ESP	Electro Static Precipitator
ETEC	Energy Technology Consultants
FC	Fixed Carbon
FWEC	Foster Wheeler Energy Corp.
GPC	Georgia Power Company
GR/DSCF	Grains Per Dry Standard Cubic Foot
ICCT	Innovative Clean Coal Technology
ICT	Innovative Combustion Technologies, Inc.
LNB	Low NOx Burners
LOI	Loss on Ignition
MMBtu	Million British Thermal Units
MW	Megawatts
MWe	Megawatts Electrical
NSPS	New Source performance Standard
PSIG	Pounds per Square Inch Gage
PTC	Power Test Code
SCS	Southern Company Services, Inc.
SoRI	Southern Research Institute
THC	Total Hydrocarbons
VM	Volatile Matter
WSPC	W.S. Pitts Consulting, Inc.

1.0 INTRODUCTION

This Innovative Clean Coal Technology II project to evaluate NOx control techniques on a 500 MWe utility boiler is funded by three organizations:

1) U.S. Department of Energy (DOE),
2) The Southern Company
and 3) Electric Power Research Institute (EPRI).

The Georgia Power Company (GPC) provided Hammond Unit 4 as the host site. GPC also provided on-site assistance and coordination for the project. The project is being managed by Southern Company Services, Inc. (SCS) on behalf of the project. co-funders. The Southern electric system includes five electric operating companies: Alabama Power, Georgia Power, Gulf Power, Mississippi Power, and Savannah Electric and Power. SCS provides engineering, research, and financial services to the Southern electric system. The following briefly describes the overall organization and describes in detail the organization related to the test and evaluation activities.

This report is provided to document the testing performed and results achieved during Phase 3B - Low NOx Burner Retrofit with Advanced Overfire Air (AOFA). This effort began in May 1993 following completion of Phase 3A - Low-NOx Burner Testing. The Phase 1 baseline effort and results were documented in the Southern Company Services report titled as "500 MWe Demonstration of Advanced Wall-Fired Combustion Techniques for the Reduction of Nitrogen Oxides (NOx) Emissions from Coal-Fired Boilers - Phase 1 Baseline Tests Report" (1). The Phase 2 effort and results are documented in "500 MWe Demonstration of Advanced Wall-Fired Combustion Techniques for the Reduction of Nitrogen Oxides (NOx) Emissions from Coal-Fired Boilers - Phase 2 Overfire Air Tests" (2). The Phase 3A effort and results are documented in "500 MWe Demonstration of Advanced Wall-Fired Combustion Techniques for the Reduction of Nitrogen Oxides (NOx) Emissions from Coal-Fired Boilers - Phase 3A Low-NOx Burner Tests" (3).

The Phase 1 and Phase 2 Reports contain a detailed descriptions of the program, test plans and testing procedures. While the present report contains sufficient background material to provide an understanding of the program scope, testing procedures and the relationship of the Phase 3B testing to the overall program, the reader is referred to the previous documents for detailed descriptions of the program, test methods, and unit configuration.

1.1 Project Description

On December 20, 1989, Southern Company Services was awarded a DOE Innovative Clean Coal Technology Round n (ICCT) contract for the project, "500 MWe Demonstration of Advanced, Wall-Fired Combustion Techniques for the Reduction of Nitrogen Oxide (NOx) Emissions from Coal-Fired Boilers". With the completion of the Phase 3B effort, the project has investigated a series of NOx reduction techniques on Unit 4 a. Georgia Power Company's Plant Hammond located in Rome, Georgia. The project characterized emissions and performance of a wall-fired boiler operating in the following configurations:

1) Baseline "as-found" configuration - Phase 1,
2) Retrofitted Advanced overfire air (AOFA) - Phase 2,
3) Retrofitted low NOx burners (LNB) - Phase 3A,
4) Combined AOFA and LNB configuration - Phase .3B.

The major objectives of the project were to:

1) Demonstrate (in a logical stepwise fashion) the performance of three combustion NOx control technologies, i.e., AOFA, LNB and AOFA plus LNB,

2) Determine the short-term NOx emission trends for each of the operating configurations,

3) Determine the dynamic long-term NOx emission characteristics for each of the operating configurations using sophisticated statistical techniques,

4) Evaluate progressive cost-effectiveness (i.e., dollars per ton of Nox removed) of the low NOx combustion technologies tested, and

5) Determine the effects on other combustion parameters (e.g., CO production, carbon carry-over, particulate characteristics) of applying the low NOx combustion technologies.

Each of the four phases of the project involved three distinct testing periods: short-term characterization, long-term characterization and short-term verification. The short-term characterization testing established the trends of NOx versus various parameters and establishes the influence of the operating mode on other combustion parameters. The long-term characterization testing (50 to 80 continuous days of testing) established the dynamic response of the NOx emissions to all of the influencing parameters encountered. The short-term verification testing documented any fundamental changes in NOx emissions characteristics that may have occurred during the long-term test period.

1.2 Project Organization

Southern Company Services who directs in-house (SCS) and GPC personnel to perform various duties related to site coordination design engineering, environmental matters and cost coordination, and has overall responsibility for the execution of this project. Southern Company Services also directs subcontracted efforts of the burner manufacturer, installation contractors and test coordination contractor, supplying the NOx emissions control systems as described below.

Energy Technology Consultants Inc. ETEC has responsibility for the on-site testing and analysis of the data obtained for all phases of the project, serving as the test coordinator and results engineer under Southern Company Services direction. ETEC is responsible for overall management of the test efforts, including preparation of test plans, coordination and on-site direction of the test and data analysis contractors, analysis and interpretation of short-term data and preparation of the interim reports.

Spectrum Systems. Inc. Spectrum provides a full-time, on-site instrument technician who is responsible for operation and maintenance of the data acquisition system (DAS) housed within the instrument control room. For the full duration of the program (short-term characterization, long-term characterization and short-term verification for all four phases), Spectrum maintains and repairs, as necessary, the instrumentation system and monitors the function of the data acquisition system on a daily basis.

Southern Research Institute (SoRI) SoRI is responsible for testing related to flue gas particulate measurements during the performance testing portion of the short-term characterization for all four project phases. In addition to the testing activities, SoRI is responsible for ESP modeling efforts for each of the four phases.

Innovative Combustion Technologies, Inc.(ICT) ICT is responsible for activities related to fuel/air input parameters and furnace output temperature measurements during the performance testing portion of the short-term characterization for all four phases.

W. S. Pitts Consulting Inc. (WSPC) WSPC is responsible for data analysis of the emission and performance data for the long-term characterization phases of the program.

Both raw and reduced data were archived by the subcontractors as well as by ETEC for future reference.

1.3 Hammond Unit 4 Description

Hammond Unit 4 is a Foster Wheeler Energy Corporation (FWEC) designed, opposed wall-fired boiler rated at 500 MWe with design steam conditions of 2500 psig and 1000/1000°F superheat/reheat temperatures, respectively. Six FWEC mills provide pulverized eastern bituminous coal to 24 Intervane burners arranged in a matrix of 12 (three rows of four burners) on the front and rear walls. Each mill provides coal to four burners.

Unit 4 is a balanced draft unit with two forced drain and three induced drain fans. The unit is equipped with a cold side ESP. The flue gases exit the economizer through two Ljungstrom air preheaters and into the cold side ESP, then through the induced draft fans and finally out to the stack.

1.4 Report Organization

The remainder of this report is organized into six sections. Section 2.0 provides background material for the project and describes the program methodology. Section 3.0 provides details on the instrumentation and the data collection methods. The data analyses methods for both short-term and long-term data are described in Section 4.0. The results for the short-term characterization portion of the Phase 3B effort are presented in Section 5.0. Section 6.0 provides a description of the statistical approach used to analyze the continuous emission monitor (CEM) data. Section 7.0 provides a summary of conclusions for the analyses of both the short-term and long-term data.

2.0 TEST PROGRAM DESCRIPTION

In the past, there have been a number of demonstration programs by various burner manufacturers for the purpose of evaluating the NOx reduction potential of their equipment. These demonstrations have provided only minimal amounts of information that could be used to extrapolate to the general population of utility boilers. All of these demonstrations provided only small amounts of short-term data (generally less than one day for each data point) in both pre- and post-retrofit configurations. Very few of these demonstrations have provided long-term data (on the order of months of continuous data) in the post-retrofit configuration, and none have provided long-term data in the pre-retrofit configuration. The purpose of this DOE ICCT II program is to provide detailed short- and long-term pre- and post-retrofit emission data on a number of low NOx combustion technologies applied to a wall-fired utility boiler.

The following paragraphs describe the technologies that were investigated during the four phases of this program' the general methodology used to obtain data, and the general outline of Phase 3B.

2.1 Technology Background

At the completion of the DOE ICCT II program, three basic NOx control technologies will have been demonstrated and compared to the baseline configuration. The technologies to be investigated are:

1) Advanced Overfire Air (AOFA),
2) Low NOx Burner (LNB),
and 3) Combined LNB and AOFA Operation.

Each of the technologies (or combination of technologies) will eventually be compared to the baseline configuration to ascertain the NOx reduction effectiveness. Southern Company Services contracted with Foster Wheeler Energy Corporation (FWEC) to provide the low NOx burner and AOFA hardware which have been retrofit to Hammond Unit 4.

The baseline configuration is defined as the “as found” configuration of the unit. The "as found" configuration is further defined as the configuration under which the unit has operated in the recent past prior to the retrofit activities. In the case of Hammond Unit 4, this consisted of operation with some existing burner-related problems. The results of this baseline effort will be compared to the results for subsequent phases of the overall program. The following paragraphs provide an overview of AOFA and LNB retrofits as they have been incorporated into Unit 4.

2.1.1 Advance Overfire Air System

The standard offering of overfire air ports incorporates combustion air bypass from the main burner windbox through ports above the burners. This secondary combustion air is obtained from an extension of the burner windbox and is generally integral to the main burner windbox. The portion of the combustion air diverted away from the burners drives the primary combustion stoichiometry toward a fuel rich condition which facilitates reduction of NOx. The secondary combustion air diverted above the burners to the overfire air ports provides sufficient air to complete combustion before the products reach the convective pass.

Studies by EPRI and boiler manufacturers have shown that the standard overfire air (OFA) offerings do not result in optimum NOx reduction due to inadequate mixing of the secondary air with the partially combusted products from the fuel rich burner zone. This inadequate mixing limits the effectiveness of the OFA technique. The advanced overfire air system (AOFA) provided by FWEC incorporates separate (from the windbox) injection port and duct configurations that are designed to provide increased secondary air penetration. Typical standard offerings provide penetration velocities approximately two times the furnace flow velocity. AOFA systems provide increased penetration velocities by supplying secondary air from completely separate aerodynamically designed ducts located above the existing burner windbox. The ports themselves are also designed to provide increased penetration velocities.

For Phase 2, an advanced overfire air system was retrofit to the unit. This retrofit is described in Reference 2 and consisted of addition of ductwork, dampers, various instrumentation and controls, and AOFA ports above the top row of burners on the front and rear walls of the furnace. The overfire is extracted from the two main secondary air ducts between the air flow venturis and the entrances to the combustion air windbox (east and west sides of the boiler). Figure 2-1 depicts the major components of the AOFA system.

2.1.2 Low NOx Burners

For Phases 3A and 3B, FWEC supplied their Controlled Flow-Split Flame CF/SF) burner for retrofit into the existing wall penetrations of the 24 Intervane burners. The CF/SF burner was originally developed for use on the San Juan Unit 1 of the Public Service Company of New Mexico in the mid-1970s. Subsequent to that development, modifications of the burner have been incorporated into new boilers and more recently into older boilers to comply with the Clean Air Act Amendments of 1990. Figure 2-2 schematically illustrates the CF/SF burner.

As with all of the manufacturers of new low NOx burners, FWEC's burners utilize the principle of separating the fuel and air streams in the primary combustion zone. Unique design features of the burner allow low NOx operation with shorter flames than may result from other wall-fired burner manufacturers' concepts. These "internally" staged burners accomplish NOx reduction in a similar manner to that accomplished with overfire air, but in a much more efficient manner. Internally staged burners result in significantly better-mixed final products of combustion than do overfire air ports. This low NOx burner concept was evaluated during Phase 3A of the project with the AOFA flow control dampers shut to their minimum settings. Due to the unique design features of the burner, it can be operated with or without the AOFA system described above. The combination of the CF/SF burner operation used in conjunction with the AOFA system was evaluated during Phase 3B of the project.

2.2 Program Test Elements

One of the underlying premises for the structure of the testing efforts in all of the phases of this DOE ICCT II project is that short-term tests cannot adequately characterize the true emissions of a utility boiler. As a consequence of this, the focal point of the test efforts during all phases of this project is long-term testing. Short-term testing is used

FIGURE 2-1 AOFA RETROFIT CONFIGURATION

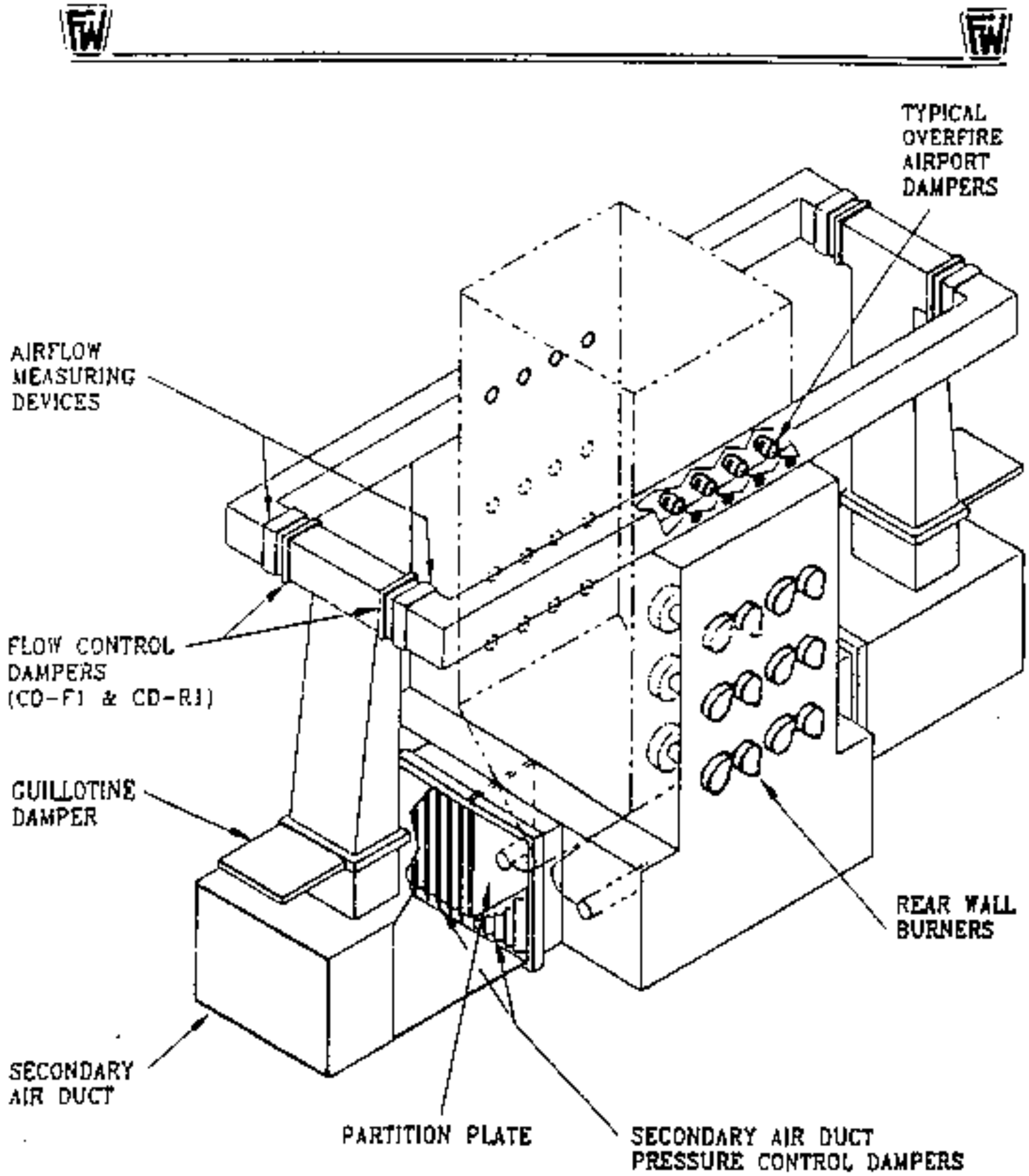
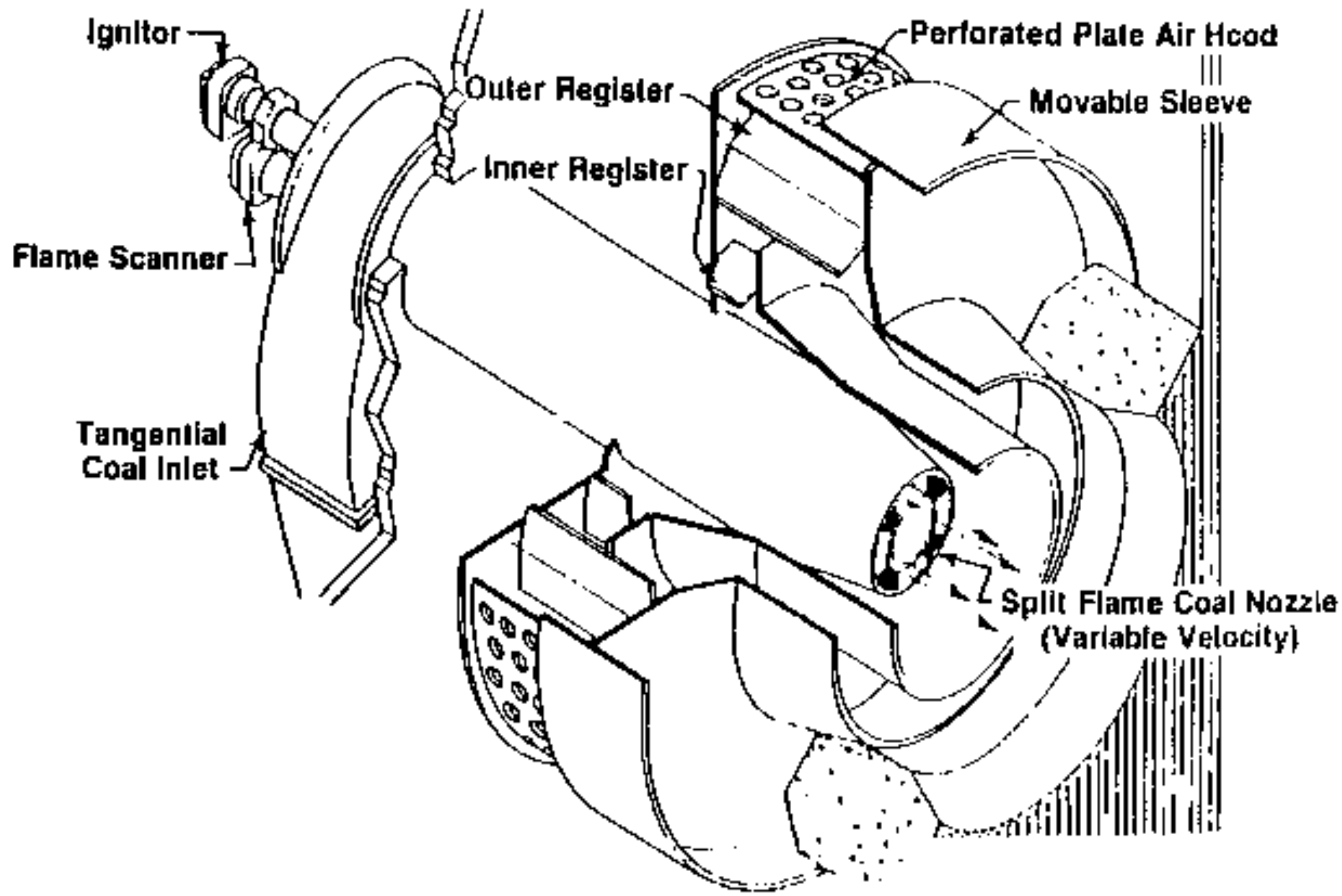


FIGURE 2-2 CONTROLLED FLOW · SPLIT FLAME BURNER SCHEMATIC



only to establish trends that may be used to extrapolate the results of this project to other similar boilers. During this program, the short-term test results are not intended to be used to determine the relative effectiveness of the retrofitted NOx control technologies. This will be accomplished by performing statistical analyses of the long-term data. A description of the purpose and sequence for each of the- three types of testing involved in all phases of the project follows.

2.2.1 Short-Term Characterization

Initial short-term testing is generally performed to establish the trends of NOx emissions under the most commonly used configurations. While NOx is comprised of NO and NO_2, only a small fraction of NOx is NO_2 (generally <5%). During this program NO was measured since the NO_2 represents a small actual incremental contribution. To account for this small contribution, significant instrumentation costs would have to be incurred. Aside from NOx measurements, short-term testing is also used to assess the performance of the boiler in the normal modes of operation. The characterization testing is divided into two elements - diagnostic tests and performance tests. Diagnostic testing is used to establish the gaseous emission trends, while performance testing is used to establish boiler efficiency and steaming capability as well as gaseous and particulate emissions and mill performance. Both diagnostic and performance tests are conducted under operating conditions controlled by the project test personnel.

Diagnostic testing involves characterizing the gaseous emissions under three to four load conditions over the range of operating parameters that might normally be encountered on Unit 4 as well as excursions about these normal conditions. The primary parameters that were used for characterization were excess oxygen, mill pattern, and mill bias. Testing at each of the selected conditions is accomplished during a one- to three-hour period with the unit in a fixed configuration while it is off of system load dispatch to ensure steady boiler operation.

Performance testing is accomplished at specified loads in configurations recommended by plant engineering and the vendor and which have been tested during the diagnostic testing. Each of these configuration represents one of the normal modes of operation for each load condition. The “nominal" burner settings were based upon initial testing by ETEC and FWEC. Performance data were recorded during ten- to twelve-hour test periods with the unit off of system load dispatch to provide steady operating conditions.

Results from each of these tests in Phase 3B (LNB + AOFA) are used for comparison with results from similar testing of the various NOx control technologies undertaken in Phases 1, 2 and 3A, i.e. Baseline, AOFA, and LNB.

2.2.2 Long-Term Characterization

Long-term testing for each phase is conducted under normal system load dispatch control conditions with the burners adjusted to the settings established by FWEC and ETEC. Generally, no intervention with respect to specifying the other operating configurations or conditions is imposed by test personnel. The long-term testing provides emission and operational results that include most if not all of the possible influencing parameters that can affect NOx emissions for a boiler over the long run. These parameters include coal variability, mill in-service patterns, mill bias ranges, excess oxygen excursions, and equipment conditions as well as many as-yet undetermined influencing parameters. Results from this long-term testing provide a true representation of the emissions from the unit. Data for the parameters of -interest are recorded continuously (5-minute averages) for periods of as long as 80 days.

2.2.3 Verification

Over the 70- to 80-day test period, changes in the unit condition and coal can occur. Verification testing is normally conducted at the end of each of the four long-term test phases for the purpose of quantifying some of the impacts of these potential changes on the long-term emission characterization. Results of this verification testing can assist in explaining potential anomalies in the long-term data statistical analysis by comparing diagnostic and verification operating conditions and fuels, i.e. controlled test conditions before and after the long-term tests. The verification tests are conducted in a similar manner to that of the diagnostic testing described above. Four to five basic test configurations (load and mill pattern) are tested during this short effort. Due to outage scheduling and forced outages, this portion of the testing was abbreviated during the Phase 3B test effort.

2.3 Phase 3B Test Plan

The Hammond Unit 4 Phase 3B testing effort was begun on May 6, 1993, and completed on August 26, 1993, including 45 days of long-term testing. The testing was interrupted periodically for various burner repairs and tuning by FWEC and other boiler maintenance work. The following briefly describes the test sequence during this period.

2.1 Short-Term Characterization Testing

The test plan for Phase 3B short-term characterization incorporated four nominal load points ranging from 180 to 480 MWe which duplicated the testing range of Phases 1, 2 and 3N Due to abnormally high opacity emissions caused by deteriorated ESP performance, much of the testing planned for 480 MWe had to be conducted at reduced loads, i.e. 440-470 MWe.

The Phase 3B diagnostic test matrix for Unit 4 was performed over the period from May 6, 1993 to August 25, 1993, which period also included performance testing. This diagnostic test matrix included the following basic test conditions:

LOAD MWe	MILL PATTERN	NO. TESTS
440-495	All Mills in Service	21
450	All Mills in Service	12
4Q0	3 MOOS Patterns	13
300	4 MOOS Patterns	9
180	1 MOOS Patterns	3

Each of these tests was performed over a duration of from one to three hours.

The performance portion of the short-term characterization tests included tests at 300, 400 and 462-480 MWe load levels, and was performed from June 17 through June 23, 1993.

2.3.2 Long-Term Characterization Testing

Long-term characterization testing began in May, 1993 and was completed in August 1993, resulting in the acquisition of 91 days of continuous emissions data.

2.3.3 Verification Testing

The limited verification testing indicated that the NOx emission characteristics of the unit did not change appreciably from the diagnostic test results.

3.0 TEST PROCEDURES AND MEASUREMENTS

A wide variety of measurement apparatus and procedures were employed during the test program described in Section 2.0. The acquisition of data can be conveniently grouped into four broad data categories relating to the equipment and procedures used. These are: manual boiler data collection, automated boiler data collection, combustion systems tests, and solid/sulfur emissions tests. A brief description *of* each data category follows. A more complete description of each category is contained in Reference 1.

1) Manual Boiler Data Collection

   Data were recorded manually onto data forms based on readings from plant instruments and controls. The data were subsequently entered manually into a computer data management program. Coal, bottom ash, and ESP hopper ash (which was taken separately from inlet and outlet. hoppers on both east and west sides of the ESP) samples were collected regularly for subsequent laboratory analysis. The addition to the data readings taken during Phase 1, readings of burner damper settings were recorded during Phase 3B.

2) Automated Boiler Data Collection

   Two scanning data loggers were installed to record the signals both from pre-existing plant instrumentation and from instruments installed specifically for this test program. The data loggers were monitored by a central computer that maintained permanent records of the data and also allowed instantaneous, real-time interface with the data acquisition equipment. In addition to the measurements provided in Phase 1, signals were recorded from four OFA flow meters, one in each OFA windbox quadrant during Phase 3B. This was done to document the low OFA flow rate due to leakage through the nominally closed OFA flow control dampers.

Specialized instrumentation was also installed to measure some specific parameters related to the combustion and thermal performance of the boiler, as well as selected gaseous pollutant emissions. These included combustion gas analyzers, pollutant emissions analyzers and continuous ash samplers. The combustion gas and emissions analyzers and the acoustic pyrometer system were linked to the central computer for automated data recording.

3) Combustion System Tests

At several specific operating conditions tests were performed by Innovative Combustion Technologies using specialized apparatus and procedures to measure parameters related to the combustion and thermal performance of the boiler. The measurements included the following:

- Primary Air/Fuel Supply
  - Primary air flow rate to each mill
  - Primary air velocity to each burner
  - Coal flow rate to each burner
  - Coal particle size distribution to each burner

- Secondary Air Supply
  - Secondary air flow and temperatures, east/west
  - Secondary air flow and temperatures, front/rear windboxes

- Overfire Air Supply
  - OFA Flow to each quadrant of OFA (Front and rear/east and west)

- Furnace Combustion Gases
  - Gas temperatures near furnace exit
  - Gas species near furnace exit

- Boiler Efficiency
  - Exit gas temperatures
  - Exit gas excess O_2
  - Unburned carbon losses

4) Solid/Sulfur Emissions Tests

During the performance tests, SoRI made measurements of particulate and gaseous emissions exiting the boiler, using specialized equipment and procedures. These measurements included:

Total particulate emissions and particle sizes Fly Ash resistivity at the ESP inlet SO_2 and SO_3 concentrations

The results of the solid/sulfur emissions tests are to be used in calculations to estimate the effect of NOx controls on the performance of a generic ESP representative of large utility installations.

4.0 DATA ANALYSIS METHODOLOGY

Two distinctly different types of data analyses are utilized to characterize the data: discrete analyses for short-term data, and statistical analysis for long-term data. The short-term data are used to establish emission trends, provide information for engineering assessments, and provide data for evaluating guarantees or goals established with the equipment vendors. Long term data are used to statistically establish the long-term emission trends and regulatory assessments when the unit is operated in a normal system load dispatch mode.

4.1 Short-Term Characterization Data Analysis

The short-term data collection portion of the project is divided into two elements: diagnostic and performance test efforts. The diagnostic data collection effort is used to establish the trends of NOx versus load, mill patterns and excess oxygen. The performance data collection effort is used to establish input/output characterizations of fuel, air, flue gas emissions and boiler efficiency. Both the diagnostic and performance efforts are performed under well-controlled conditions with the unit off of system load dispatch. Each data point is for a single operating condition. Unlike the data collected in the long-term effort, the data collected during the short-term effort is generally not of sufficient quantity to apply sophisticated mathematical analysis. Most of the analysis of the short-term data is graphical.

4.1.1 Diagnostic Data

The emphasis of the diagnostic testing is to determine the NOx characteristics of the unit. The NOx, O_2 and CO are automatically recorded every five seconds and stored in the historic files on a computer. The NOx measurements of interest during this element of the short-term testing are those obtained from the sample flow distribution manifold. The manifold allows sampling from individual probes or combinations of probes located in the economizer exit upstream of the primary and secondary air preheaters. The composite emission measurement over the entire economizer exit (average of 28 probes) for the period of a diagnostic test represents a single data point for one configuration.

A single data point is obtained by selecting a probe group and obtaining numerous one-minute averages of the five-second data over the one- to three-hour period of the test. Sampling of one of the groupings is made for a sufficient time to insure that the readings are steady. The DAS is then prompted to gather data for one minute (12 five-second readings) and to calculate the statistics for that period (e.g. average and standard deviation). The average of all of the one-minute average measurements over the test duration constitutes a single data point for NOx for the condition under which the test was performed.

Early diagnostic test efforts showed that the variability of the NOx emissions was significant for seemingly identical conditions, i.e., load, O_2 and mill pattern. Since only a limited amount of short-term data were to be collected in the diagnostic effort, the high variability jeopardized the ability to trend the emissions data adequately. If the diagnostic test effort had included many more data points (requiring significantly more test days), the approach may have provided sufficient information to perform the experimental design regression analyses. As a result of the NOx variability, the test plan reverted to a more or less sequential approach to collecting emission data, i.e., one load and mill pattern per day with a range of excess oxygen levels measured during steady-state conditions.

During the Phase 3B diagnostic testing, attempts were made to gather three sequential data points (either increasing or decreasing excess oxygen level) at each load level (or mill pattern). With three data points on one day with a minimum variation of the other influencing parameters, the general trend of NOx versus load (or mill pattern) could be determined. Test points that were not sequential (different loads or mill patterns on the same day) were used to indicate the potential variability about the trend lines. It is assumed that the trends for these single, non-sequential data points is similar to that determined for sequential data and that families of curves exist. This assumption was tested during Phase 1 and found to be true.

4.12 Performance Data

Performance data are used (1) to establish baseline evaluation criteria for retrofits, (2) to quantify the boiler characteristics for comparison with other phases of the program and (3) for comparison with the results of the diagnostic trends. The emphasis for the performance tests was on the analysis of the flows, solids capture and boiler efficiency rather than on the NOx trends. As with the diagnostic test data, insufficient data samples were available to perform meaningful advanced statistics.

For each performance configuration (10- to 12-hour test day) the following types of data were obtained:

1) Two gaseous emission measurements of NOx, O_2 and CO, each composed of at least 10 one-minute Sample Distribution Manifold composite flue gas measurements,

2) Two ASME PTC 4.1 boiler efficiency determinations and two air preheater leakage determinations,

3) A minimum of three repetitions of specific flue gas solids emission parameters (total particulate emissions, $S0_3$, resistivity, LOI, or particle size), and

4) A minimum of one repetition of inlet fuel and air measurements (primary air distribution, secondary air distribution, coal particle size, or coal mill pipe distribution), or furnace combustion gas temperature and species.

4-2 Long-Term Characterization Data Analysis

During this portion of the test program, the emission and plant operating data input was automatically recorded on the DAS and archived. The emission input was handled automatically by the CEM. A single emission measurement point in the ductwork just upstream of the stack breaching was monitored 24 hours per day during the entire long-term effort. The emission sample was brought to the CEM through heated lines to preclude condensation of SO_2 in the lines.

The primary focus of the long-term test effort was to monitor the natural variation of the data in the normal mode of operation. During the entire long-term effort, no operational intervention by the test team members occurred or was for that matter allowed. This was to insure that the long-term data would not be biased by this type of input. For all practical purposes, the boiler was operating in its normal day-to-day configuration under economic load dispatch. The only added constraint was that the new LNBs would be operated as determined during the short-term testing.

The thrust of the analysis of the long-term data is its interpretation primarily by statistical methods. The specific types of analysis used are related to regulatory issues and the engineering interpretation of long-term results compared to short-term diagnostics results The analyses related to the regulatory issues were associated with the determination of the 3-day rolling average and annual average emissions and the estimation of an achievable emission level that the data support. The analyses related to the engineering interpretations were associated with the determination of the best statistical estimates of the operating characteristics, i.e., NOx versus load, mill pattern, etc.

The following two subsections provide information on (1) the processing of the raw long-term data to produce a valid emission data set and (2) the fundamentals of the data-specific analytic techniques.

4.2.1 Data Set Construction

Five-minute Average Emission Data

The data collected during the long-term test program consisted of 5-minute averages of parameters related to boiler operating conditions and emissions. Since the intent of all analyses of the long-term test periods is to depict normal operating conditions, data collected during startup, shutdown and unit trips were excluded from the analyses.

The 5-minute average data are also used to compute hourly averages that are in turn used to compute daily average NOx emissions. The daily average emissions are used to estimate the achievable NOx emission limit.

The loss of 5-minute data due to CEM failure was treated based on an adaption of EPA NSPS guidelines for determining how much data is sufficient to compute an hourly average for emissions monitoring purposes. Also, in the case of daily average emissions, EPA NSPS guidelines (at least 18 hours of valid hourly data per day) were used to define a valid daily average.

4.2.2 Data Analysis Procedures

Five-minute Average Emission Data

The edited 5-minute average data from the long-term tests were used to determine (1) the NOx versus load relationship and (2) the NOx versus O_2 response for various load levels.

Hourly Average Emission Data

The purpose of the hourly average emission analyses was to assess the hour-to-hour variation in NOx, 0_2, and load for these periods. The within-day data analyses are performed by sorting the hourly averages by hour of the day and computing the average NOx, 0_2, and load for these periods. The statistical properties for these hourly periods and the upper 95 and lower 5 percentile band was determined for each hourly data subset. These data will be used to compare the effectiveness of each technology against the baseline load scenario.

Daily Average Emission Data

The daily average emission data are used primarily to establish the trends in NOx, O_2 and load, and to calculate the 3-day rolling NOx emission levels for the entire long-term period. The daily average emissions data were analyzed both graphically and statistically. The graphical analyses consist of a series of plots to depict the daily variations in NOx, O_2 and load to establish trends. The purpose of the statistical analyses was to determine the population mean, variability (standard deviation), distributional form (normal, lognormal), and time series (autocorrelation) properties of the 24-hour average NOx e missions. The SAS Institute statistical analysis packages UNIVARIATE and AUTOREG were used to perform the statistical analyses.

Achievable Emission Rate

The results of the UNIVARIATE and AUTOREG analyses were used to determine the achievable emission limit on a 3-day rolling average and an annual (block 365 day) basis. The achievable emission limit on a 3-day rolling average basis is defined as the value that will be exceeded, on average, no more than one time per ten years. This compliance level is consistent with the level used by EPA in the NSPS Subpart Da and Db rulemakings. The achievable emission limitation for an annual average NOx emission limitation was also determined to reflect the requirements of the CAAA 90. A compliance level of 95 percent was chosen for this case.

The achievable emission limit can be computed analytically using the following relationship if the emissions data are normally distributed:

Z = (L- X) / (SAva)

where: Z = the standard normal deviate

L = the emission limit

X = the long-term mean, and

S_{AVG} = the standard deviation of the 3-day averages. S_{AVG} is computed using the estimated standard deviation (SDay) and autocorrelation (r) level for daily averages.

For 30-day averages:

$$S30 = \frac{SDay}{\sqrt{30}} \left(\frac{1 + p}{1 - p} - \frac{(2)(p)(1 - p^{30})}{30\,(1 - p)^2} \right)^{1/2}$$

For 365-day averages:

$$S365 = \frac{SDay}{\sqrt{365}} \left(\frac{1+\rho}{1-\rho} - \frac{(2)(\rho)(1-\rho^{365})}{365\,(1-\rho)^2} \right)^{1/2}$$

Since there are 3,650 30-day rolling averages in ten years, one exceedance per ten years is equivalent to a compliance level of (3649/3650), or 0.999726. For a compliance level of one violation in ten years, Z is determined to be 3.46 (based upon the cumulative area under the normal curve). The calculation of the annual average emission limitation is performed in a manner similar to that for the 30-day limitation. For annual averages, a 95 percent compliance level was arbitrarily chosen. The Z value for 95 percent compliance is 1.645.

5.0 SHORT-TERM TEST RESULTS

The short-term testing consisted of first performing diagnostic testing to establish the general NOx and operating trends followed by performance testing to establish the characteristics of the fuel/air feed systems and the solid and gaseous emissions for the most representative configuration. Following the performance testing, the NOx emissions and unit operating parameters were monitored continuously, 24-hrs per day, for a period of 95 days (long-term testing, see Section 6.0). At the end of the long-term test period a short series of verification tests was conducted, similar to diagnostic testing, to determine whether any change had occurred in the basic unit emission characteristics over the long-term period. All tests during the diagnostic, performance, and verification portions of the short-term test effort were conducted within the normal limits of operating parameters for the unit, with the exception of excess oxygen. Excess oxygen was exercised well above and below the plant specified range at each load level to the potential levels that might be encountered during transients in the long-term test phase. All major boiler components, as well as ancillary equipment, were in the normal "as found" operating condition. The fuel burned throughout the Phase 3B short-term program was from the normal supply source and was handled according to common plant practice. For all Phase 3B testing (LNB with AOFA) the main OFA guillotine dampers and OFA port dampers were full open and the OFA flow control dampers were nominally open to the settings recommended by FWEC over the load range. For some diagnostic and verification tests the OFA flow control dampers were opened more or less than the nominal settings to determine the effects of OFA flow on NOx emissions and on operating parameters. For all tests, the OFA flow was read from the OFA flowmeter readouts in the control room, which represented the air flows to the front and rear, east and west quadrants of the OFA windbox. During the Performance testing, additional measurements were made of the air flow into each OFA quadrant by means of pitot traverses performed in accordance with ASME test procedures.

The following paragraphs describe the diagnostic, performance and verification testing performed during Phase 3B.

5.1 Diagnostic Tests

The initial Phase 3B short-term characterization testing was begun on May 6, 1993 and was completed on August 26, 1993. A total of 53 diagnostic tests was performed during this period. The Phase 3B diagnostic effort consisted of characterizing emissions under normal operating conditions with the LNBs installed and the AOFA {low control dampers opened to the settings recommended by FWEC, as well as greater and lesser settings. The tests were performed at nominal loads of 180, 300, 400, 450 and 480 MWe. The diagnostic test efforts were interrupted to accomplish the performance testing due to scheduling conflicts. Diagnostic testing was then completed after the performance testing was completed. The initial diagnostic testing began shortly after FWEC completed start-up testing for the LNB/AOFA configuration. Each test condition (load, excess oxygen, OFA flow and mill configuration) was held steady for a period of from one to three hours depending upon the type of test performed. During this period, manual data were collected from the control room, automated boiler operational data were recorded on the DAS, and economizer exit and preheater exit gas species and temperatures were recorded utilizing the sample distribution manifold and were recorded on the DAS. When sufficient time permitted, furnace backpass ash grab samples were collected from the CEGRIT ash samplers and coal samples were collected from the individual pulverizer feeders.

5.1.1 Unit Operating Condition

During the diagnostic test efforts no unusual operating conditions were encountered that placed restrictions on the test effort, except that testing at high load was at times restricted by high opacity emissions. For that reason, some 450 MWe tests were conducted when the 480 MWe level could not be reached without excessive opacity.

Table 5-1 presents the "as tested" conditions during the diagnostic portion of the testing. Sixteen days of testing were executed comprising the 53 various excess oxygen, mill pattern, OFA and load conditions. Because historic load profiles indicated much greater operating times at 400 MWe and above, compared to lower loads, diagnostic testing was done more extensively at the higher load levels.

TABLE 5-1
SUMMARY OF HAMMOND UNIT 4 PHASE 3B DIAGNOSTIC TESTING

TEST NO.	DATE	TEST CONDITIONS	LOAD (MW)	MOOS PATTERN	OFA FLOW KPPH	DAS 02 DRY (%)	NOx lbs/Mbtu
101-1	05/06/93	HI-LOAD OFA VARIATION	449	AMIS	600	3.5	0.465
101-2	05/06/93	HI-LOAD OFA VARIATION	452	AMIS	455	3.6	0.488
101-3	05/06/93	HI-LOAD OFA VARIATION	446	AMIS	300	3.6	0.525
102-1	05/07/93	MID-LOAD O2 VARIATION	394	AMIS	400	4.4	0.479
102-2	05/07/93	MID-LOAD O2 VARIATION	397	AMIS	400	3.3	0.404
102-3	05/07/93	MID-LOAD O2 VARIATION	397	AMIS	400	2.7	0.349
102-4	05/07/93	HI-LOAD BASELINE	479	AMIS	763	3.1	0.405
103-1	05/08/93	MID-LOAD MILL VARIATION	407	E	310	4.1	0.492
103-2	05/08/93	MID-LOAD O2 VARIATION	402	B	320	4.6	0.476
103-3	05/08/93	MID-LOAD O2 VARIATION	398	B	300	4.0	0.440
103-4	05/08/93	MID-LOAD O2 VARIATION	399	B	303	3.1	0.365
104-1	05/09/93	LO-LOAD O2 VARIATION	305	D&F	305	5.2	0.344
104-2	05/09/93	LO-LOAD O2 VARIATION	295	D&F	295	3.9	0.286
105-1	05/10/93	MID-LOAD MILL/OW VARIATION	395	F	300	3.9	0.362
105-2	05/10/93	MID-LOAD MILL/OW VARIATION	396	F	344	5.1	0.442
106-1	06/08/93	HI-LOAD OFA VARIATION	450	AMIS	595	3.6	0.367
106-2	06/08/93	HI-LOAD OFA VARIATION	477	AMIS	794	3.9	0.391
106-3	06/08/93	HI-LOAD OFA VARIATION	468	AMIS	829	4.5	0.441
107-1	06/09/93	HI-LOAD NOMINAL	465	AMIS	813	4.0	0.501
108-1	06/10/93	HI-LOAD O2 VARIATION	463	AMIS	824	4.1	0.395
108-2	06/10/93	HI-LOAD O2 VARIATION	449	AMIS	792	3.8	0.371
108-3	06/10/93	HI-LOAD O2 VARIATION	472	AMIS	802	3.1	0.651
109-1	06/11/93	HI-LOAD OFA VARIATION	470	AMIS	797	3.7	0.380
109-2	06/11/93	HI-LOAD OFA VARIATION	490	AMIS	952	3.5	0.369
109-3	06/11/93	HI-LOAD OFA VARIATION	474	AMIS	611	3.6	0.405
110-1	06/12/93	LO-LOAD MILL/O2 VARIATION	302	E	314	5.3	0.404
110-2	06/12/93	LO-LOAD MILL/O2 VARIATION	305	B&E	250	4.6	0.318
110-3	06/12/93	LO-LOAD MILL/O2 VARIATION	305	B&E	326	5.5	0.369
110-4	06/12/93	LO-LOAD MILL/O2 VARIATION	302	B&E	315	6.4	0.421
110-5	06/12/93	MID-LOAD O2 VARIATION	394	B	327	5.6	0.489
110-6	06/12/93	MID-LOAD O2 VARIATION	391	B	313	4.3	0.402
110-7	06/12/93	MID-LOAD O2 VARIATION	391	B	403	4.3	0.377
111-1	06/13/93	LO-LOAD MILL/O2 VARIATION	293	B&D	310	6.3	0.410
111-2	06/13/93	LO-LOAD MILL/O2 VARIATION	295	B&D	317	5.0	0.345
111-3	06/13/93	LO-LOAD MILL/O2 VARIATION	292	B&D	306	4.3	0.309
112-1	06/14/93	MID-LOAD NOMINAL O2	400	AMIS	396	4.3	0.423
112-2	06/14/93	MID-LOAD O2 VARIATION	400	TEST	ABORTED	MILL	PROBLEMS
112-3	06/14/93	MID-LOAD NOMINAL O2	404	AMIS	416	4.7	0.447
113-1	06/15/93	HI-LOAD OFA VARIATION	476	AMIS	799	3.8	0.395
113-2	06/15/93	HI-LOAD OFA VARIATION	474	AMIS	585	3.6	0.422
113-3	06/15/93	HI-LOAD OFA VARIATION	474	AMIS	276	3.4	0.451
114-1	06/16/93	MIN-LOAD O2 VARIATION	179	B,D,E	94	6.8	0.412
114-2	06/16/93	MIN-LOAD O2 VARIATION	186	B,D,E	93	5.4	0.377
114-3	06/16/93	MIN-LOAD O2 VARIATION	183	B,D,E	90	4.5	0.346
121-1	06/24/93	HI-LOAD OFA VARIATION	483	AMIS	954	3.7	0.411
121-2	06/24/93	HI-LOAD OFA VARIATION	482	AMIS	791	3.9	0.413
121-3	06/24/93	HI-LOAD OFA VARIATION	481	AMIS	603	3.8	0.414
121-4	06/24/93	HI-LOAD OFA VARIATION	495	AMIS	777	3.8	0.421
122-1	06/25/93	MID-LOAD MILL/O2 VARIATIONS	401	AMIS	409	4.0	0.365
122-2	06/25/93	MID-LOAD MILL/O2 VARIATIONS	402	AMIS	275	4.1	0.399
122-3	06/25/93	MID-LOAD MILL/O2 VARIATIONS	397	AMIS	516	4.2	0.348
122-4	06/25/93	MID-LOAD MILL/O2 VARIATIONS	396	AMIS	510	4.7	0.385
122-5	06/25/93	MID-LOAD MILL/O2 VARIATIONS	395	AMIS	401	4.7	0.404
122-6	06/25/93	MID-LOAD MILL/O2 VARIATIONS	392	AMIS	395	3.3	0.321

5.1.2 Gaseous Emissions

During both the diagnostic and performance test efforts, flue gas data and boiler operating data were collected on the data acquisition system (DAS). The gas analysis system (GAS) allowed measurement of NO, CO, O_2 and total hydrocarbons (THC) from 48 probe locations within the flue gas stream both upstream and downstream of the air preheater. Two basic types of tests were performed - overall NOx characterization and economizer exit plane species distribution characterization. The overall NOx characterization tests were performed over a period of approximately one hour and were used to obtain composite average specie concentrations from the individual probes in a duct sampled as a group. In general, the groups were 1) A-side economizer outlet, 2) Beside economizer outlet, 3) A & B economizer outlet composite, and 4) Stack inlet dust concentrations. The economizer exit plane species distribution characterizations were performed over a period of approximately two to three hours. These tests used data from the individual probe species concentrations in, the A- and Beside economizer exit planes to establish the extent of maldistribution of combustion products emanating from the boiler. These maldistributions are an indication of the uniformity of combustion due either to fuel and/or air non-uniformities.

Table 5-2 presents a summary of important emission and operating parameters recorded on the DAS during the diagnostic test effort. These operating parameters provide information on the steaming conditions and the fuel supply configuration. The range of excess oxygen and resulting NOx emissions for the four nominal load levels tested during the diagnostic portion of the Phase 3B effort are shown in Figures 5-1 and 5-2. The conditions represented in these figures include the tested ranges of excess oxygen variation, mill-out-of-service variation, mill biasing, OFA flow, etc.

Figure 5-1 illustrates that the testing was performed over a range of excess oxygen levels that were both below and above the levels recommended for this unit. The solid line represents the recommended minimum excess oxygen operating level over the load range. During system dispatch control of the unit, excursions to the extreme O_2 levels are frequently experienced during transient load conditions. Thus, the range of excess O_2 levels was tested to permit a valid comparison between the short-term and long-term emission characteristics.

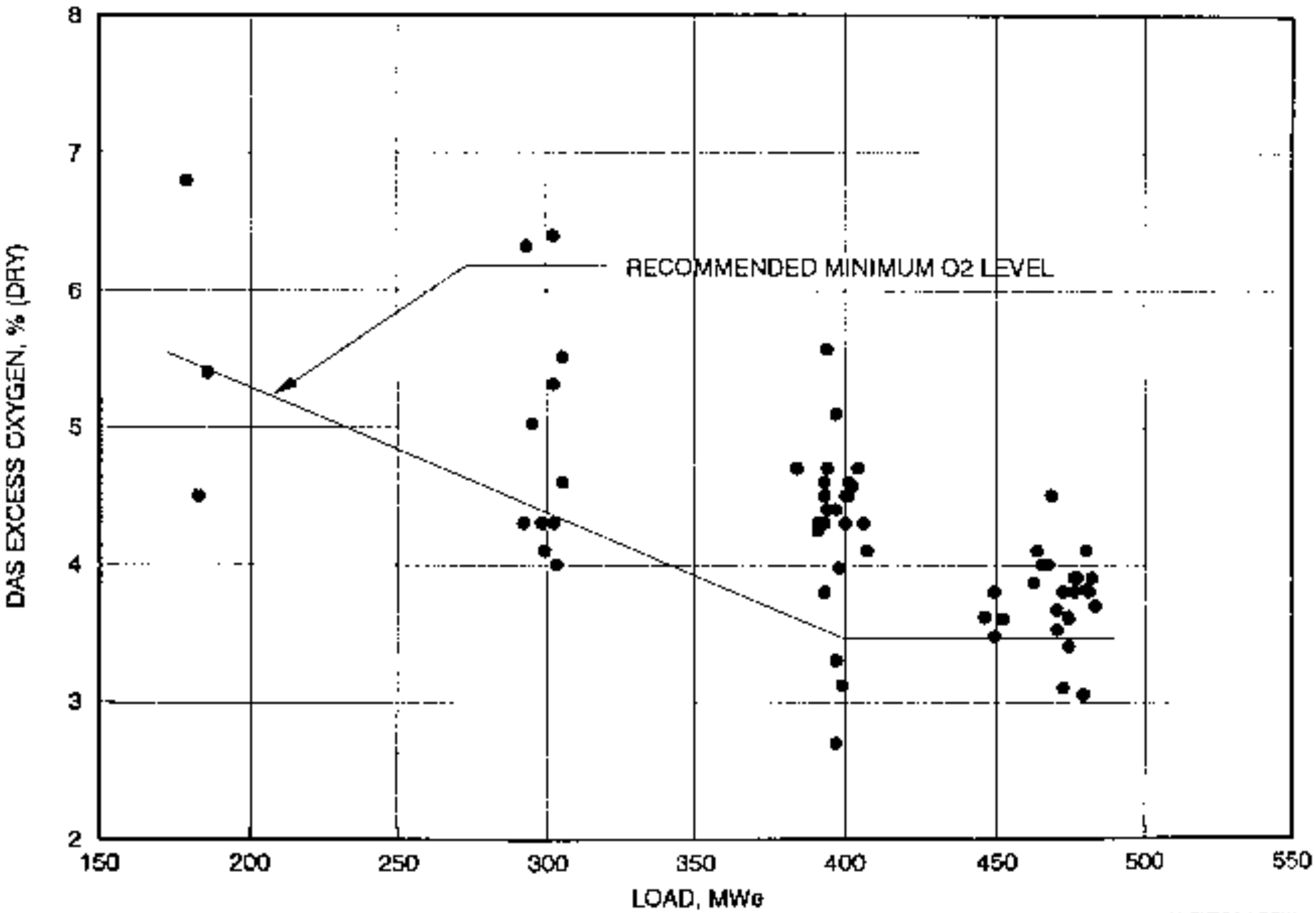
TABLE 5-2 SUMMARY OF PHASE 3B DIAGNOSTIC TESTS OPERATING AND EMISSION DATA

TEST NO.	DATE	GROSS LOAD (MWE)	PLANT O2 E ECON OUTLET (DRY %)	PLANT O2 W ECON OUTLET (DRY%)	CEM O2 AVERAGE OUTLET (DRY%)	CEM AVG NOx COMPSOITE AT 3% O2 (PPM)	STACK OPACITY (PCT)	SAPHA OUT TEMP (Deg. F)	SAPAH B OUT TEMP (Deg. F)	STEAM FLOW (MLB/HI
101-1	05/06/93	444	3.8	3.4	3.5	334	27.6	317	310	2.86
101-2	05/06/93	447	3.7	3.7	3.6	380	28.1	325	315	2.85
101-3	05/06/93	444	3.5	3.8	3.6	380	28.7	326	318	2.87
102-1	05/07/93	393	4.4	4.7	4.4	350	23.0	311	291	2.50
102-2	05/07/93	394	3.6	3.4	3.6	360	20.2	319	308	1.72
102-3	05/07/93	393	3.3	2.5	2.6	255	20.8	324	310	2.45
102-4	05/07/93	471	3.1	2.6	2.6	290	39.0	340	325	3.30
103-1	05/08/93	402	4.1	4.3	4.1	356	23.3	303	293	2.54
103-2	05/08/93	399	5.0	4.6	4.7	350	26.4	306	300	2.52
103-3	05/08/93	394	4.3	4.1	3.9	320	23.7	307	301	2.50
103-4	05/08/93	395	3.5	3.3	3.1	287	20.3	305	299	2.50
104-1	05/09/93	302	5.0	5.9	5.3	251	14.0	294	266	1.76
104-2	05/09/93	295	3.5	4.5	4.0	210	13.0	300	273	1.80
105-1	05/10/93	302	3.8	4.1	3.9	282	25.5	300	289	2.48
105-2	05/10/93	301	4.9	5.9	5.1	319	29.0	311	298	2.48
106-1	06/08//93	450	3.0	2.4	3.6	270	30.0	329	316	3.08
106-2	06/08/93	482	3.5	3.1	3.9	284	29.7	340	328	3.25
106-3	06/08/93	475	3.8	3.6	4.5	320	31.4	341	330	3.20
107-1	06/09/93	483	3.9	3.7	4..1	385	21.8	334	323	3.07
108-1	06/10/93	485	4.0	3.7	4.1	290	22.2	321	310	310
108-2	06/10/93	453	3.8	3.2	3.7	268	20.9	333	347	3.03
108-3	06/10/93	472	3.3	2.5	3.0	256	24.7	335	321	3.12
109-1	06/11/93	472	3.4	3.1	3.7	280	27.1	322	310	3.15
109-2	06/11/93	471	3.4	3.1	3.8	270	19.0	327	317	3.11
109-3	06/11/93	481	3.2	3.6	3.6	290	22.4	335	329	3.14
110-1	06/12/93	300	4.8	4.0	5.3	290	10.6	298	284	1.88
110-2	06/12/93	305	3.6	3.7	4.5	230	9.9	294	278	1.89
110-3	06/12/93	305	4.3	5.0	5.5	268	9.7	293	283	1.88
110-4	06/12/93	302	5.6	5.9	6.4	307	10.4	291	288	1.85
110-5	06/12/93	395	4.9	5.4	5.5	350	20.2	323	316	2.53
110-6	06/12/93	395	4.0	4.2	4.2	290	15.9	320	314	2.53
110-7	06/12/93	391	4.0	4.1	4.2	271	16.2	319	314	2.51

TABLE 5-2 (Continued) SUMMARY OF PHASE 3B DIAGNOSTIC TESTS OPERATING AND EMISSION DATA

			PLANT O2		CEM O2	CEM AVG NOx				
TEST NO.	DATE	GROSS LOAD (MWE)	E ECON OUTLET (DRY %)	W ECON OUTLET (DRY%)	AVERAGE OUTLET (DRY%)	COMPSOITE AT 3% O2 (PPM)	STACK OPACITY (PCT)	SAPHA OUT TEMP (Deg. F)	SAPAH B OUT TEMP (Deg. F)	STEAM FLOW (MLB/HR)
111-1	06/13/93	295	5.0	6.4	6.2	292	9.4	268	289	1.82
111-2	06/13/93	294	4.1	5.4	5.0	250	9.6	281	279	1.82
111-3	06/13/93	293	3.6	4.4	4.3	224	9.6	285	278	1.80
112-1	06/14/93	400	3.8	4.7	4.4	314	33.3	308	299	2.56
112-3	06/14/93	404	3.8	5.0	4.7	326	17.7	312	306	2.58
113-1	06/15/93	478	3.8	3.4	3.8	290	42.0	323	317	3.11
113-2	06/15/93	474	3.5	3.0	3.8	305	35.7	325	321	3.12
113-3	06/15/93	474	3.2	3.2	3.3	330	28.0	328	322	3.10
114-1	06/16/93	178	6.2	6.7	6.8	300	7.0	271	266	1.08
114-2	06/16/93	177	5.1	5.5	5.5	277	6.2	277	275	1.14
114-3	06/16/93	181	4.5	4.8	4.5	255	6.0	282	262	1.11
121-1	06/24/93	477	3.6	3.3	3.7	300	20.7	328	318	3.22
121-2	06/24/93	478	3.5	3.6	3.9	300	19.4	332	321	3.23
121-3	06/24/93	478	3.4	3.5	3.8	302	21.2	336	325	3.10
121-4	06/24/93	492	3.6	3.5	3.8	310	24.0	325	415	3.35
122-1	06/25/93	396	3.3	4.2	4.0	267	15.0	308	417	2.56
122-2	06/25/93	398	3.3	4.0	4.1	290	16.5	309	419	2.57
122-3	06/25/93	393	3.3	3.8	4.2	255	16.4	308	420	2.54
122-4	06/25/93	394	4.1	4.0	4.7	281	17.1	308	421	2.52
122-5	06/25/93	391	4.4	3.9	4.7	298	14.7	310	426	2.51
122-6	06/25/93	391	3.3	2.5	3.3	235	13.8	317	431	2.50
123-1	08/09/93	296	4.6	INOP	4.4	259	12.4	305	282	1.90
123-2	08/10/93	294	5.4	INOP	5.3	291	13.7	303	280	1.83
123-3	08/10/93	301	4.2	INOP	3.7	240	13.1	306	285	1.90
123-4	08/10/93	302	4.5	INOP	4.2	255	13.2	307	281	1.90
123-5	08/10/93	300	3.9	INOP	4.4	262	12.1	297	271	1.77
124-1	08/10/93	380	4.8	INOP	4.5	304	32.5	306	304	2.36
125-1	08/24/93	395	4.6	3.7	5.1	319	15.4	308	296	2.65
125-2	08/25/93	391	3.6	2.9	3.8	216	13.8	311	297	2.60
125-3	08/25/93	394	4.4	3.3	4.5	295	14.0	308	300	2.60
125-4	08/25/93	394	4.8	3.3	4.7	280	14.7	305	300	2.61
125-5	08/25/93	383	4.2	3.2	4.5	302	12.7	305	300	2.59
126-1	08/26/93	478	3.8	2.3	4.1	302	27.8	330	325	3.20

FIGURE 5-1 HAMMOND UNIT 4 OXYGEN LEVELS TESTED
PHASE 3B - LNB + AOFA



E:\SCS\FREE\RHAM3B\FIG5-1.DRW

FIGURE 5-2 HAMMOND UNIT 4 NITRIC OXIDE MEASUREMENT
PHASE 3B - LNB + AOFA

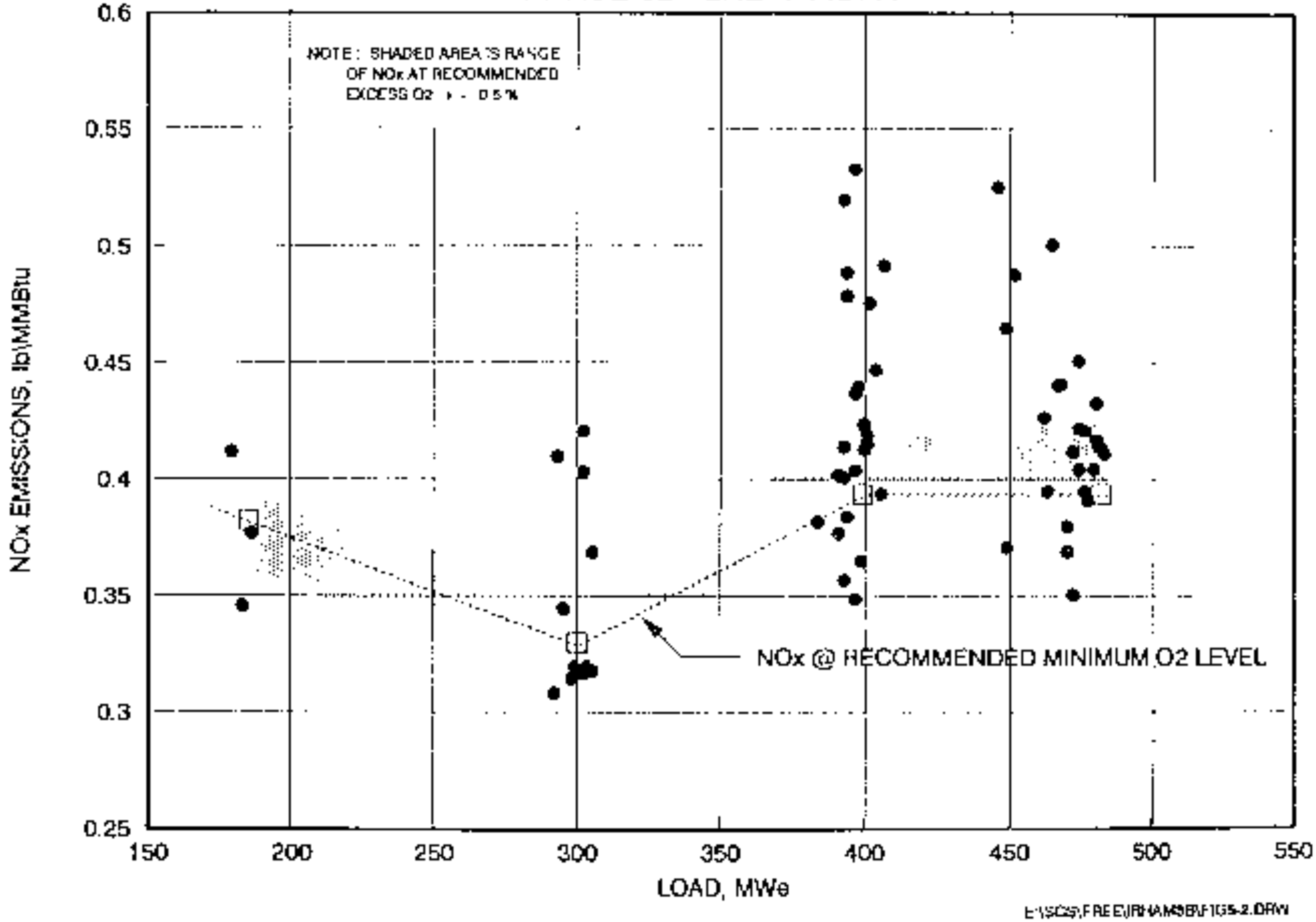


Figure 5-2 is a summary of all of the NOx data obtained for all test configurations. These configurations represented the range of normal configurations that were believed to be the predominant modes of operation that might be experienced during the system load dispatch mode of operation during long-term testing. The data scatter is partially due to the fact the different firing configurations are represented. The shaded area represents the range of NOx values experienced at excess O_2 levels within a ±10.5% O_2 variation about the recommended O_2 level and with nominal OFA flow. It should be emphasized that analyses performed for data gathered during the long-term testing (Section 6.1), where virtually thousands of data points were used for the characterization, provide a more statistically appropriate NOx band than that presented in Figure 5-2.

Short-term characterization of the NOx emissions generally were made for trends determined on the same day of testing for a particular configuration to eliminate, to some extent, the influence of the uncontrollable parameters. Figures 5-3 through 5-6 show the diagnostic test results for the four nominal loads tested - 480, 400, 30() and 180 MWe, respectively. Data shown in these figures are for the nominal overfire air flow recommended by FWEC at each load. The legend for each data point indicates the test day and run for the data point in the format X-Y, where X is the test day and Y is the run. In addition to the 480 MWe nominal load condition, a number of 450 MWe tests were conducted due to the periodic difficulty in achieving the 480 MWe load level. The inability to achieve the nominal 480 MWe load condition was due to deteriorating performance of the unit ESP which is scheduled to be replaced entirely following the conclusion of the Phase 3B testing. These data are listed in Table 5-1.

Over the load range from 480 to 180 MWe, the NOx sensitivity with excess oxygen excursions varied from 0.076 to 0.029 lb/MMBtu per percent O_2. A trend did not exist with respect to the sensitivities - the highest sensitivity was at 400 MWe while the lowest was at the 180 MWe load point. This is inconsistent with results from other test phases where the sensitivity decreased with decreasing load. The explanation for this inconsistency is unknown at this time. One possibility is that insufficient data were gathered to estimate a representative sensitivity at each load point.

FIGURE 5-3 NOx CHARACTERIZATION @ 480 MWe NOMINAL LOAD
PHASE 3B - LNB + AOFA

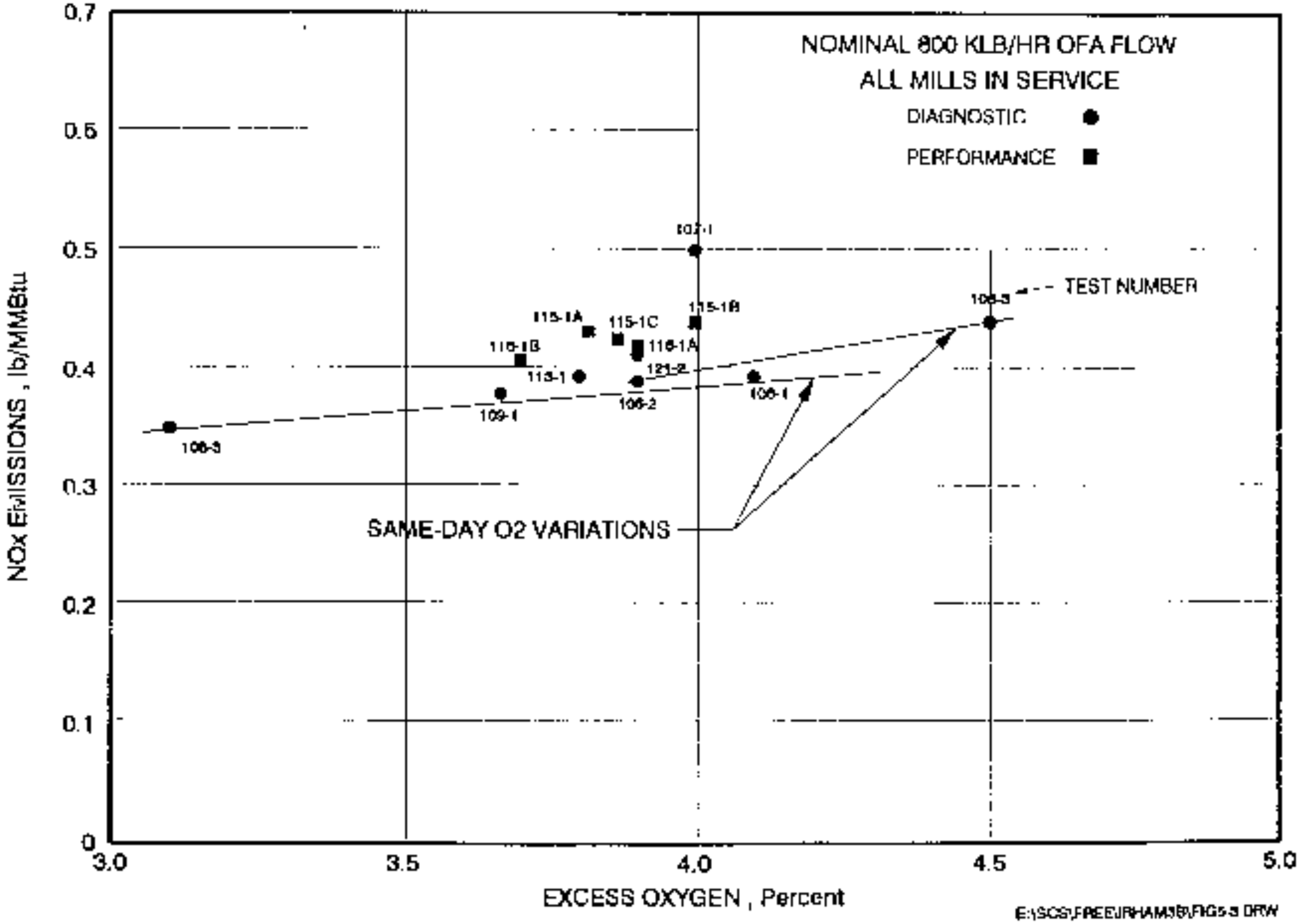
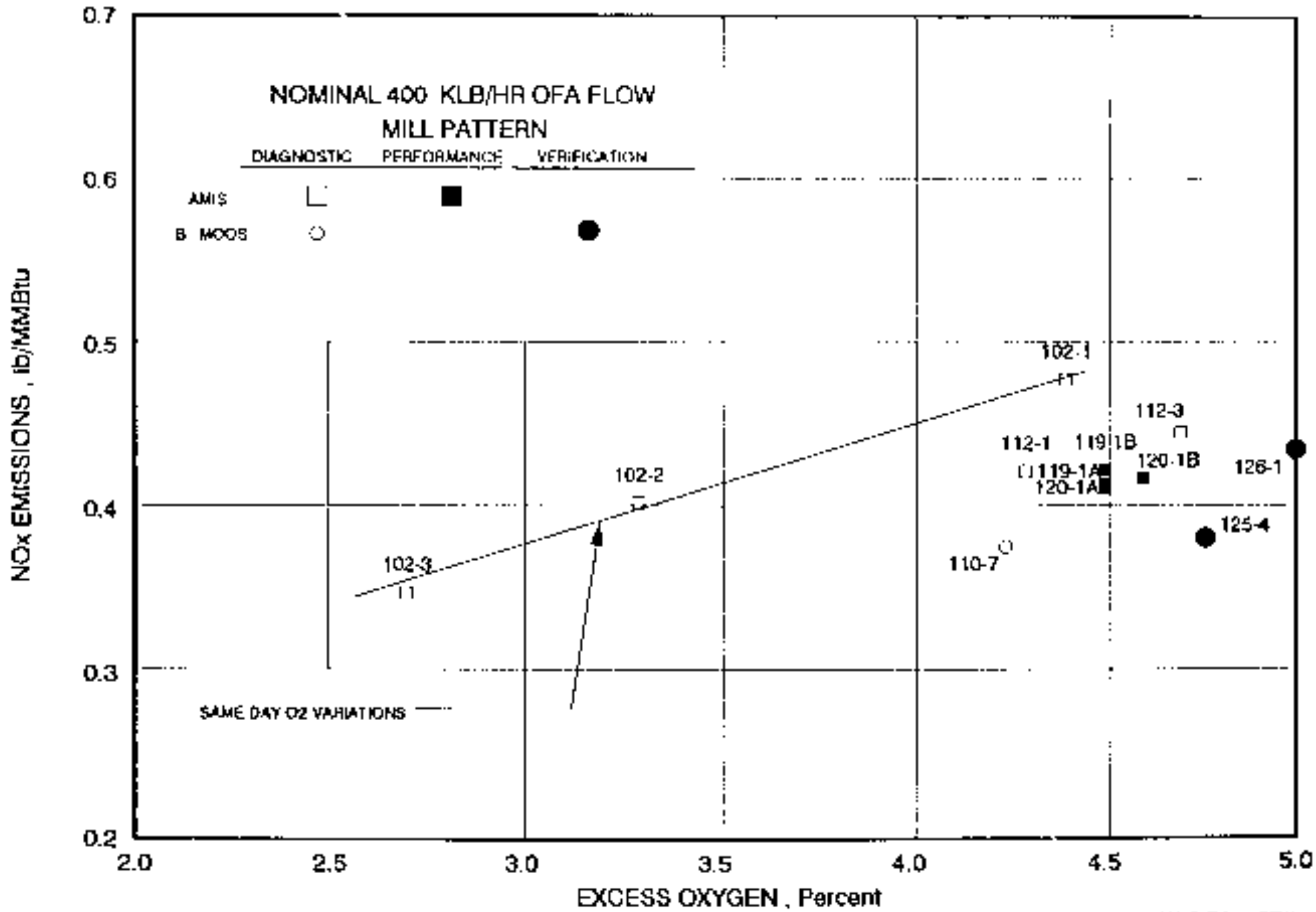
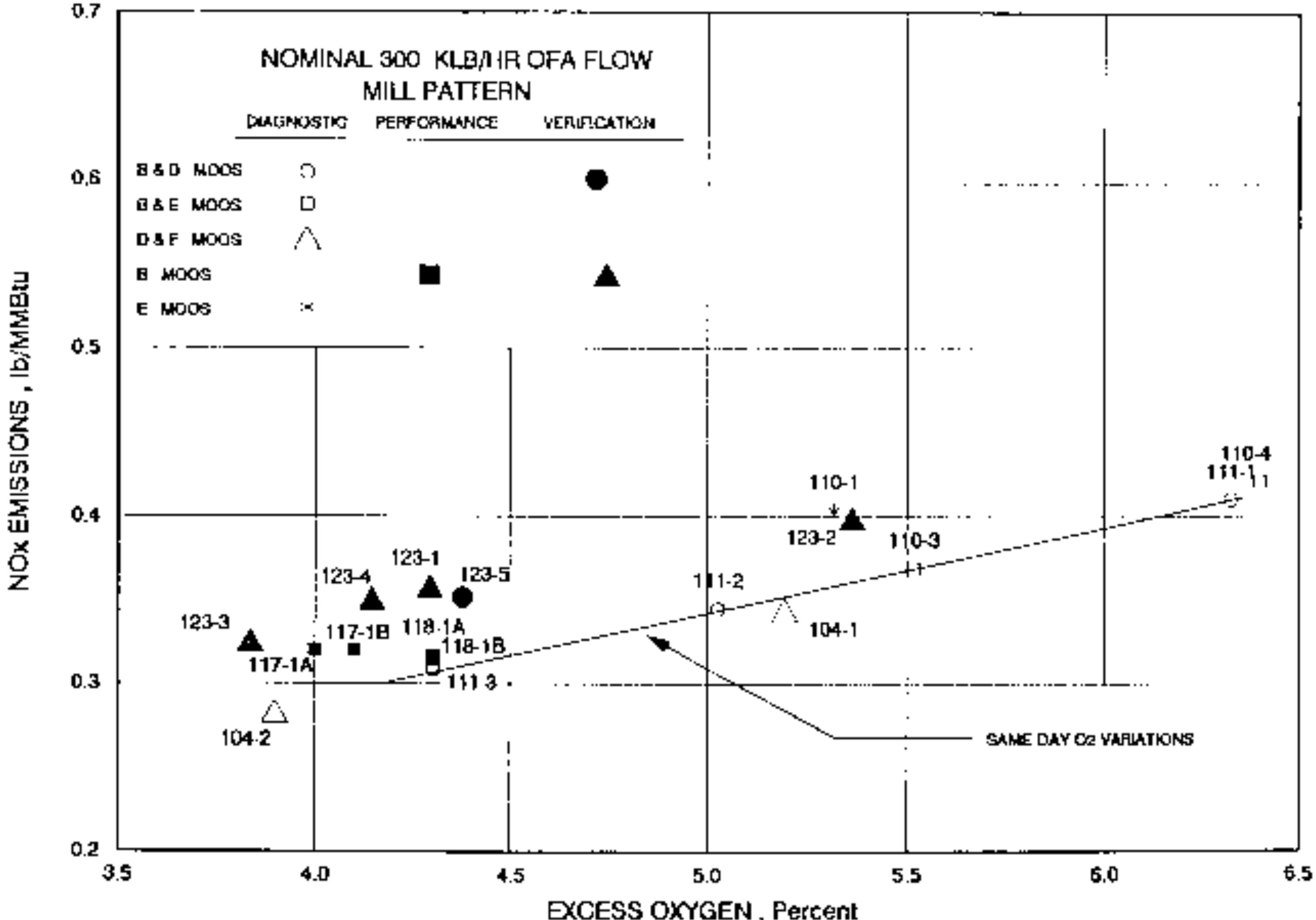


FIGURE 5-4 NOx CHARACTERIZATION @ 400 MWe NOMINAL LOAD
PHASE 3B - LNB + AOFA



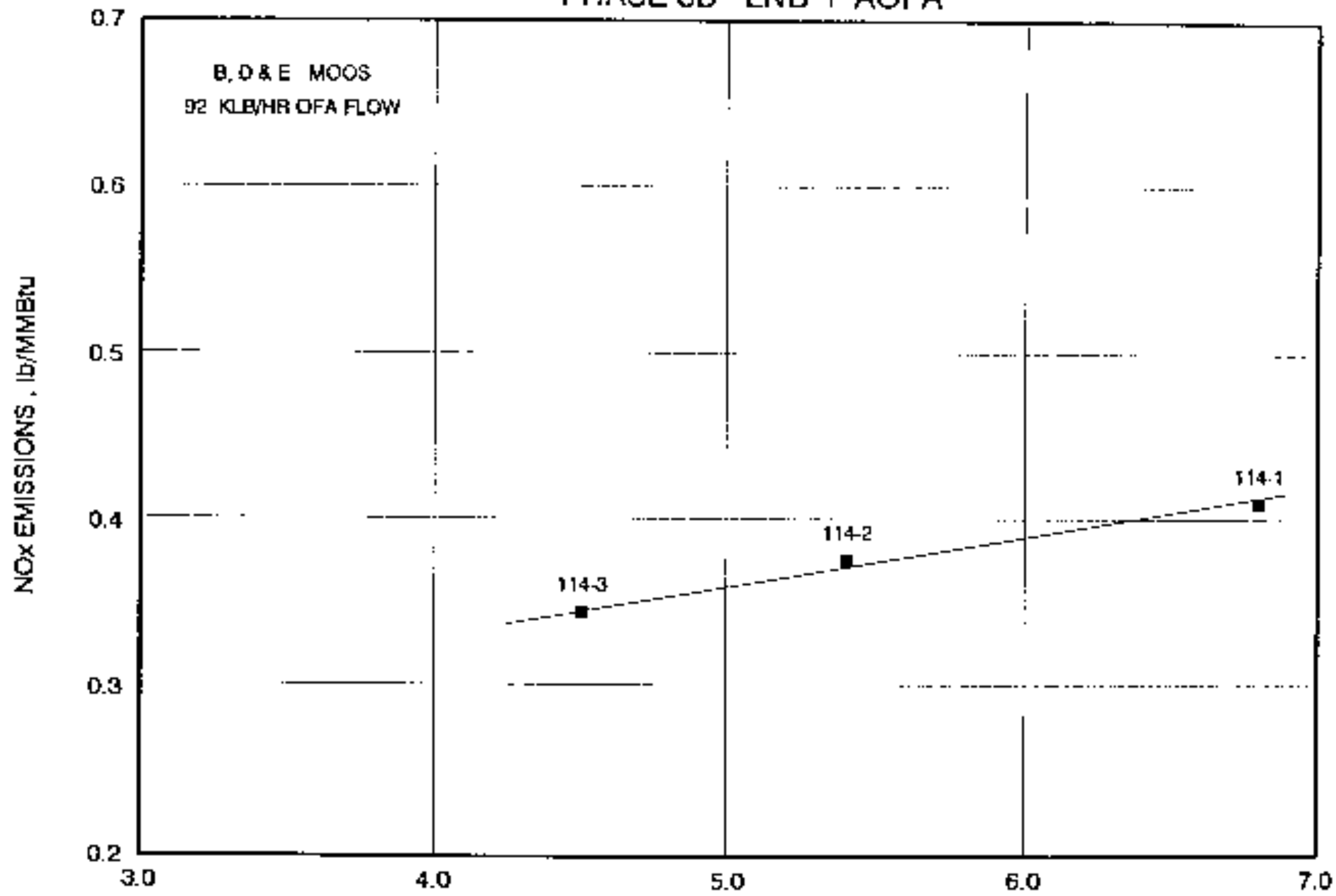
E:\SCS\FREE\IRHAM\3B\FIG5-4.DRW

FIGURE 5-5 NOx CHARACTERIZATION @ 300 MWe NOMINAL LOAD PHASE 3B - LNB + AOFA



E:\SCS\FREE\RI\AM3B\FIG5-5.DRW

FIGURE 5-6 NOx CHARACTERIZATION @ 180 MWe NOMINAL LOAD
PHASE 3B - LNB + AOFA



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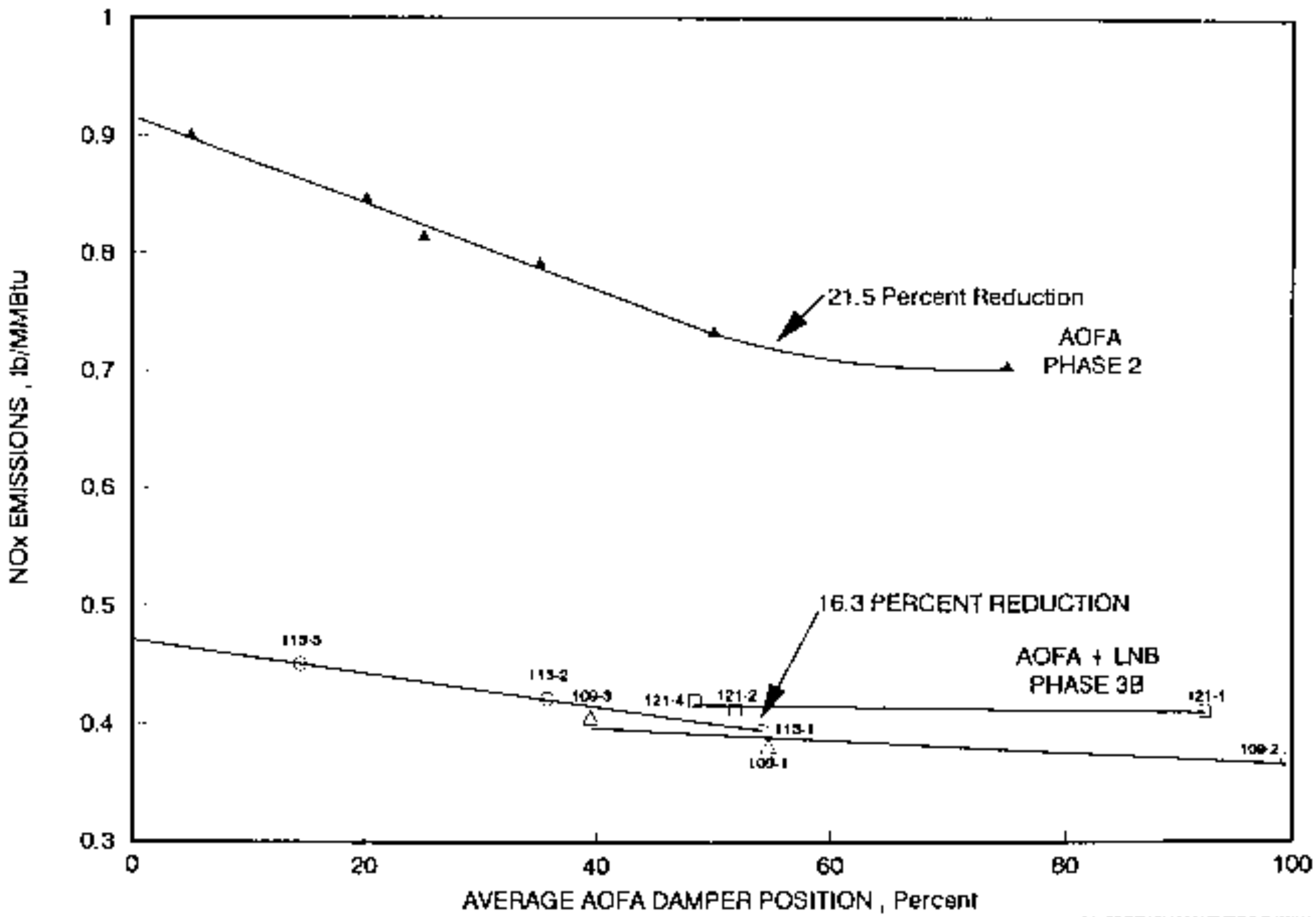
During the Phase 3B test effort, a number of tests were performed to establish the sensitivity of NOx emissions with AOFA port opening. The ports could only be closed to the limit that allowed sufficient cooling air to prevent slag buildup at the AOFA opening. Figure 5-7 illustrates the sensitivity of NOx emissions to AOFA port opening for the Phase 3B effort and for the Phase 3A effort (AOFA alone) at 480 MWe. In both the Phase 3A and 3B efforts, it was not possible to close the AOFA ports completely. In the case of Phase 3A, the AOFA ports had some leakage air past the dampers. In the case of Phase 3B, the AOFA ports were not closed completely to prevent slag buildup. In both phases it is evident that the no flow NOx level can be determined by extrapolation of the data to the closed damper position. The normal AOFA position at 480 MWe for both phases was approximately 55 percent open.

From Figure 5-7 it is evident that the effect of AOFA was less for the Phase 3B configuration with LNB plus AOFA than for the Phase 3A configuration with AOFA alone. For the AOFA only configuration the NOx emissions sensitivity between 0 and 55 percent damper position was approximately 0.0035 lb/MMBtu per percent damper opening while in the LNB plus AOFA configuration it was 0.0014 lb/MMBtu per percent damper opening position - less than one-half the sensitivity As would be expected, operation of AOFA with LNB results in lower effectiveness than for operation of AOFA alone. In the AOFA only configuration, the NOx reduction was approximately 21 percent (at 55 percent damper position) while in the LNB plus AOFA configuration it was approximately 16 percent. As will be shown in the evaluation of the long-term data in Section 6.0, the apparent AOFA reduction between Phase 3A and 3B was in the order of 40 percent. This apparent anomaly can be explained by examining the mill operation (Section 5.2.5 and Section 6.5.2) in both phases and the results of the Special LOI Testing described in the Phase 3A Interim Report.

5.2 Performance Tests

Six performance tests were conducted at nominal gross loads of 480, 400 and 300 MWe. Testing at each load point required two consecutive days to complete sampling of all of the parameters included in the performance matrix. At each nominal load the coal firing rate was kept as constant as possible and the electric load allowed to swing slightly as affected by coal variations, boiler ash deposits, ambient temperature, etc. The unit

FIGURE 5-7 COMPARISON OF AOFA EFFECTIVENESS
PHASE 2 VERSUS PHASE 3B



E:\SCS\FRED\PHAM3B\FIG5-7.DRW

excess O_2 and OFA flow rates were maintained as recommended by FWEC at each load level. The coal feed rate to all in-service pulverizers was kept as nearly equal as possible, based upon the control room coal feeder readouts. Subsequent to the completion of the Phase 3B long-term testing, it was discovered that the control room feeder readings did not represent the actual mill coal flow rates as will be explained in Section 5.2.4. Each performance test covered a period from ten to twelve hours during which time manual and automated boiler operational data were recorded, fuel and ash samples acquired, gaseous and solid emissions measurements made, fly ash resistivity measured in-situ, and the engineering performance tests conducted.

5.2.1 Unit Operating Data

For each performance test, the desired test conditions were established and allowed to stabilize at least one hour prior to commencement of testing. To the extent possible the active coal mills were balanced with respect to control room coal feeder rate meters (subsequently discovered to be inaccurate). Normal primary air/coal ratios and mill outlet temperatures were maintained, within the capacity of the existing primary air system. When the desired operating conditions were established, some controls were placed in manual mode to minimize fluctuations in the fuel or air firing rate. This technique resulted in extremely stable operation over the test duration with only minor adjustment to the air flow over the day to maintain a near-constant stoichiometry.

Because a portion of the testing was concerned with measurement of various particulate emission characteristics, it was decided that soot blowing (both furnace and air preheaters) should be suspended during the particulate sampling periods, so that the test measurements would include only particulate matter actually generated by the coal combustion at the time of testing (plus any normal attrition of wall or air preheater deposits) and not periodic portions of ash loosened by soot blowing. When necessary for proper unit operation, air preheaters were blown between repetitions in the solids emissions testing.

Table 5-3 presents a summary of important operating parameters recorded on the DAS during this test series. The values shown in this table represent averages over the duration of the test segment during the day.

TABLE 5-3
SUMMARY OF HAMMOND UNIT 4 PHASE 3B PERFORMANCE TESTING

TEST NO.	DATE	TEST CONDITIONS	LOAD MWe	MOOS PATTERN	OFA FLOW (KPPH)	DAS O2 DRY (%)	NOX EMISSIONS (lb/mmBtu)	CO	COMP LOI ppm	COMP CARBON
115-1A	06/17/93	PERFORMANCE TEST 480 MWe	480	AMIS	790	3.8	0.433	31	8.000	7.200
115-1B	06/17-93	PERFORMANCE TEST 480 MWe	467	AMIS	784	4.0	0.441	29		
115-1C	06/17/93	PERFORMANCE TEST 480 MWe	462	AMIS	774	3.9	0.427	38		
116-1A	06/18/93	PERFORMANCE TEST 480 MWe	476	AMIS	787	3.9	0.421	54		
116-1B	06/18/93	PERFORMANCE TEST 480 MWe	472	AMIS	805	3.8	0.412	300		
117-1A	06/19/93	PERFORMANCE TEST 300 MWe	303	B	311	4.0	0.320	62	5.700	5.200
117-1B	06/19/93	PERFORMANCE TEST 300 MWe	299	B	297	4.0	0.320	40		
118-1A	06/20/93	PERFORMANCE TEST 300 MWe	302	b	321	4.3	0.317	37		
118-1B	06/20-93	PERFORMANCE TEST 300 MWe	298	B	308	4.3	0.315	41		
119-1A	06/21/93	PERFORMANCE TEST 400 MWe	400	B	427	4.5	0.413	105	6.400	5.600
119-1B	06/22/93	PERFORMANCE TEST 400 MWe	400	B	409	4.5	0.424	123		
120-1A	06/22/93	PERFORMANCE TEST 400 MWe	401	B	421	4.5	0.415	87		
120-1B	06/23/93	PERFORMANCE TEST 400 MWe	401	B	424	4.6	0.419	91		

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5.2.2 Gaseous Emissions

During the performance tests, gaseous emissions were measured with the CEM operating in the manual mode. At various times during the performance tests, flue gas was sampled from selected probes or probe groups in the primary and secondary air preheater inlet and outlet ducts. These groupings consisted of composites of the individual east and west economizer exit ducts and individual measurements from each probe in these ducts. Composite grouping was performed to establish the overall emission characteristics while the individual probe measurements were made to establish spatial distributions of emission species. Composite average values of O_2 and NOx measured during each test segment are shown in Table 54 along with a variety of unit operating parameters recorded from the control room instruments.

5.2.3 Solid Emissions

Ash particulate emissions were measured both for total mass emission rate and for characteristic properties related to ash collection within an ESP. The specific measurements and analyses that were performed included 1) total mass emissions, 2) particle size, 3) chemical composition, 4) ash resistivity, and 5) SO_3 concentration in the flue gas. These measurements were made immediately after the air preheater. The following paragraphs describe a portion of the results of these measurements made by Southern Research Institute.

Total mass emissions reflect both a fraction of the total coal ash injected into the furnace (100 percent minus the ash which drops into the furnace bottom hopper or the economizer hopper), plus most, if not all, of any unburned carbon leaving the flame zone. Table 5-5 presents the results of the Method 17 tests performed (see Section 3.0) at each test condition. The results shown for each test represent the average of three replicate samples.

As a measure of the degree of completeness of combustion, the ash collected in the cyclone portion of the Method 17 train for each test was analyzed for carbon content and loss-on-ignition (LOI). The LOI is considered to represent carbon content along with volatile solids (sulfates, chlorides, etc.) driven off in the analysis procedure. The

TABLE 5-4 SUMMARY OF PHASE 3B PERFORMANCE TESTS OPERATING AND EMISSION DATA

TEST NO.	DATE	GROSS LOAD MWe	PLANT 02 E ECON OUTLET (DRY %)	PLANT 02 W ECON OUTLET (DRY %)	CEM O2 AVERAGE OUTLET (DRY%)	CEM Nox COMPOSITE AT 3% O2 (PPM)	STACK OPACITY (%)	SAPH A OUT TEMP (DEG F)	SAPH B OUT TEMP (DEG F)	STEM FLOW (MLB/HR)	SH TEMP (DEG F)
115-1	06/17/93	470	3.5	3.9	3.8	310	20.1	331	320	3.30	998
116-1	06/18/93	472	3.5	3.8	3.9	305	21.8	325	318	3.20	994
117-1	06/19/93	296	4.2	4.1	3.9	239	9.0	303	304	1.90	980
118-1	06/20/93	302	4.0	4.5	4.2	230	7.3	229	300	1.86	997
119-1	06/21/93	396	4.7	3.7	4.4	305	17.9	310	309	2.57	987
120-1	06/22/93	396	4.6	3.8	4.5	305	14.2	315	309	2.60	995

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principal use of the performance test LOI analyses is as a reference for comparison with ash samples acquired during other phases of the program.

TABLE 5-5

SUMMARY OF SOLID MASS EMISSIONS TESTS

TEST No.	LOAD Mwe	O2 Percent	LOADING gr/dscf	GAS FLOW ACFM	CARBON	LOI
115	472	4.0	2.98	2,123,000	7.2	8.0
117	301	4.0	2.92	1,324,000	5.2	5.7
119	400	4.2	2.96	1,816,000	5.6	6.4

5.2.4 Combustion System Tests

As in the Phase 1 baseline testing, combustion performance tests were performed at each of three load levels to document the specific performance parameters related to the fuel and air combustion systems. The results of the Phase 3B performance testing, summarized below, are documented in the ICT test report.

Mill Performance The air flow to each mill and the particle size and mass flow distributions of coal to each burner were measured as described in Section 3.3. Tests were performed at three load levels (480, 300 and 400 MWe). Table 5-6 summarizes the results of these tests. From Table 5-6 it can be seen that, despite the mills being set to approximately equal coal flows with the boiler controls based upon control room instrumentation the measured coal flows varied considerably from mill to mill. This trend is shown in Figure 5-8 for the 480 MWe load test. Also, the measured PA flow rates varied considerably, producing a wide range of Fuel/PA ratios. It should be noted that the pipe-to-pipe variations in coal mass flow rates are large (over 3:1 for test 115) - indicating that the localized flame stoichiometry within the furnace may be highly non-uniform. The coal fineness was excellent for all mills except B & D, the two remaining older mills currently scheduled for replacement.

Figure 5-9 shows the mill configuration of Hammond Unit 4. Based upon the measured mill flows, it can be shown that the furnace was operating in a significant mill bias mode. This is illustrated in Figure 5-10 for the deviation of the flows from the mean at each level (lower, middle and top). This configuration was shown in the Phase 3A Interim Test Report to have a significant effect on NOx emissions. The bias with more coal flow to the top row of mills than the bottom row produced the lowest NOx emission of any of the bias configuration during the Phase 3A Special LOI Test program. Figure 5-11 illustrates the measured mill flow deviation for the Phase 3A test effort which shows that the bias was not the optimum for minimizing NOx emissions. As will be discussed in Section 6.0, this difference in the mill flows between Phases 3A and 3B may explain the low NOx emission levels achieved during Phase 3B.

Secondary Air Supply The total secondary combustion air flow was measured at the main secondary air supply ducts and at each corner (quadrant) of the OFA windbox. Table 5-7 presents the results of the primary, secondary and OFA air flow measurements. This data indicates that the overfire air flow represented approximately 20 percent of the total combustion air flow.

5.2.5 Coal and Ash Analyses

During each of the nine days of Phase 3B performance testing, samples were obtained of coal entering the active mills, furnace fly ash (CEGRIT), fly ash collected in the ESP (east and west sides) and bottom ash.

FIGURE 5-8 COMPARISON OF MEASURE AND CONTROL ROOM MILL FLOWS

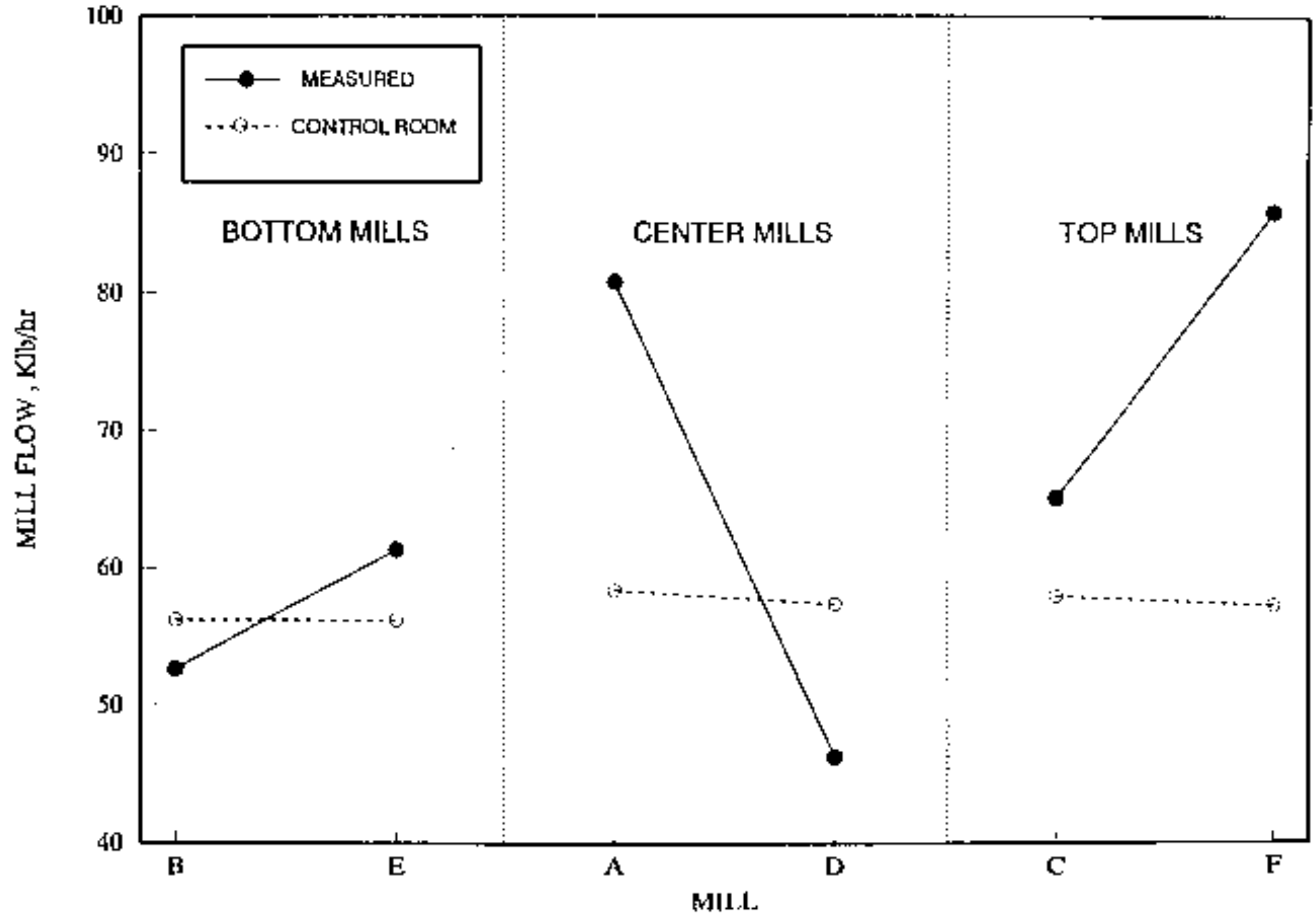

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FIGURE 5-9

HAMMOND UNIT 4 BURNER LAYOUT

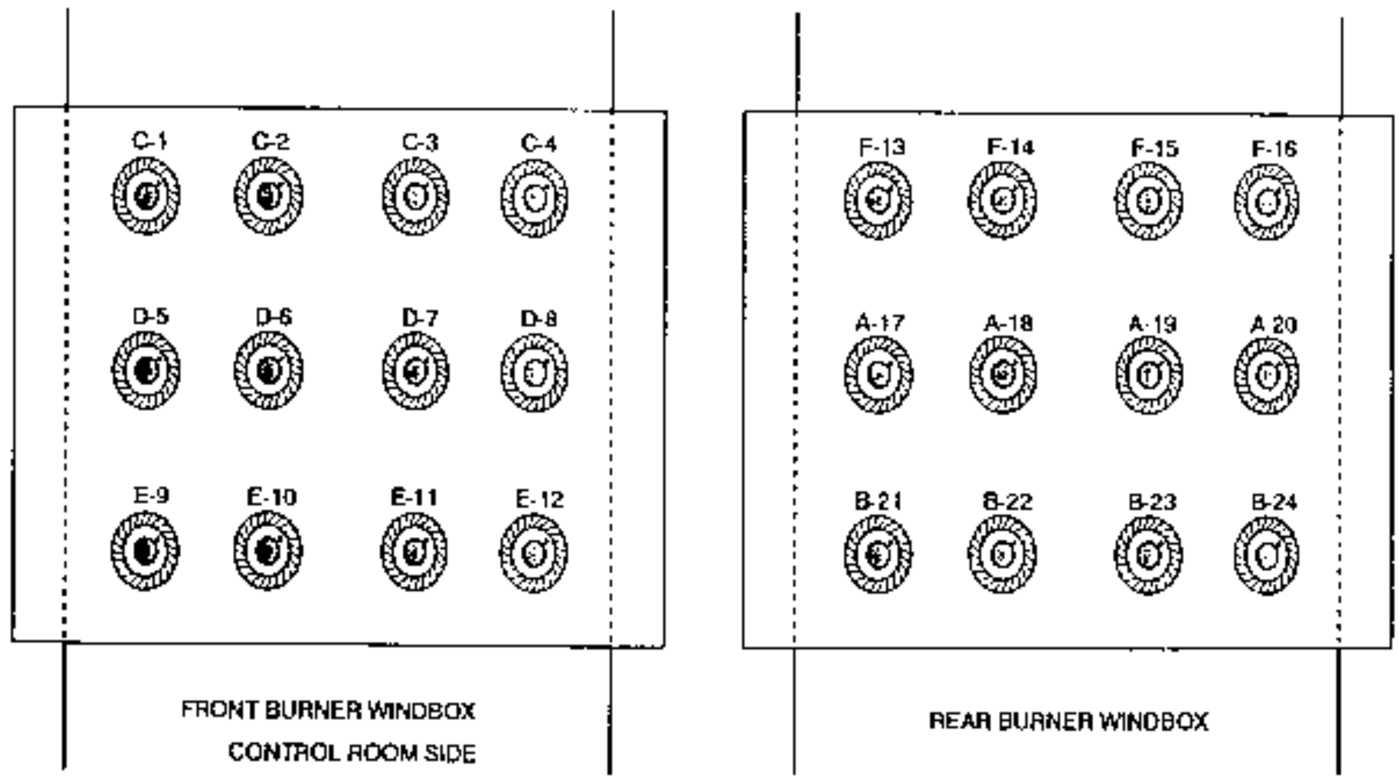

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FIGURE 5-10 PHASE 3B MILL BIAS

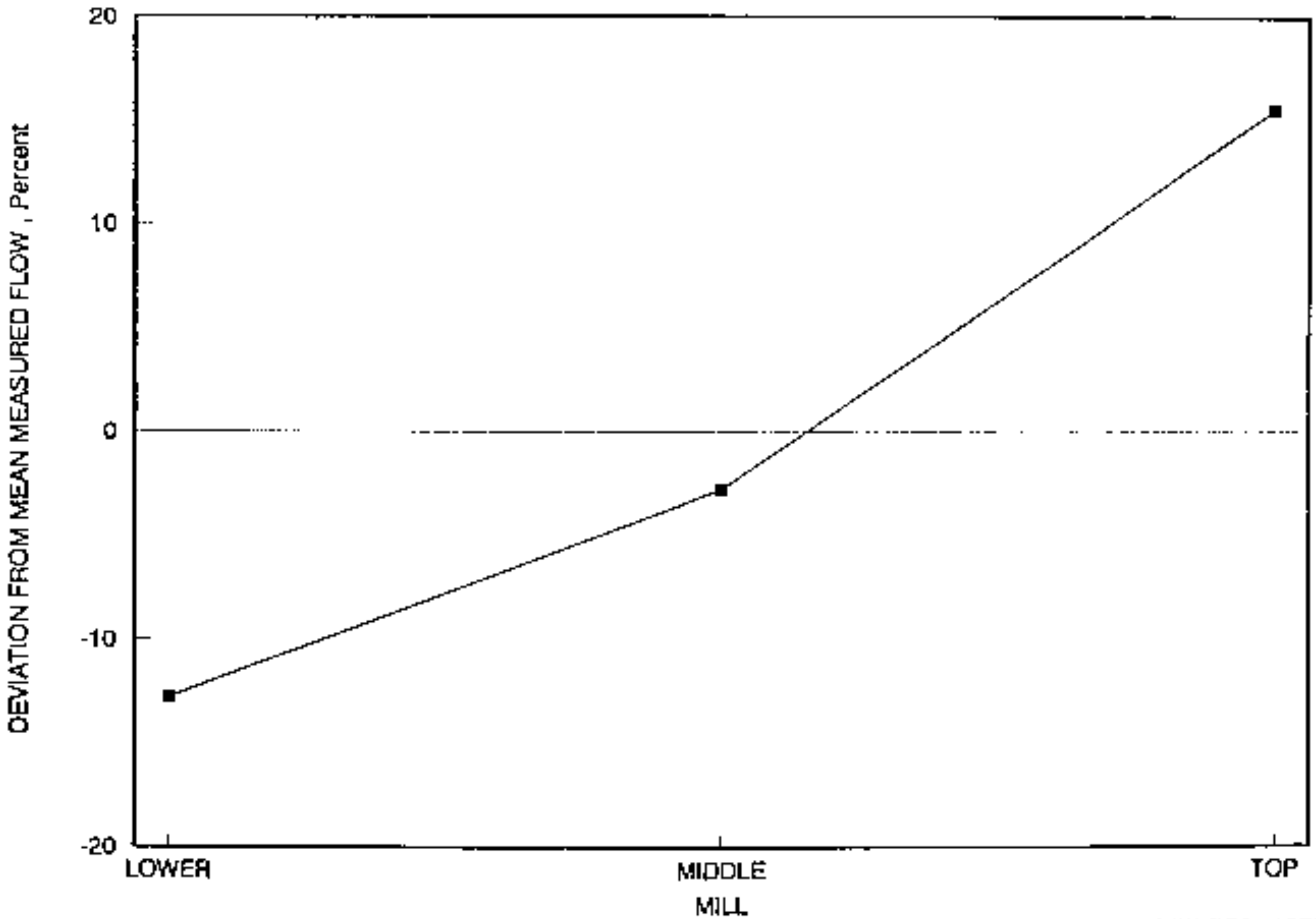

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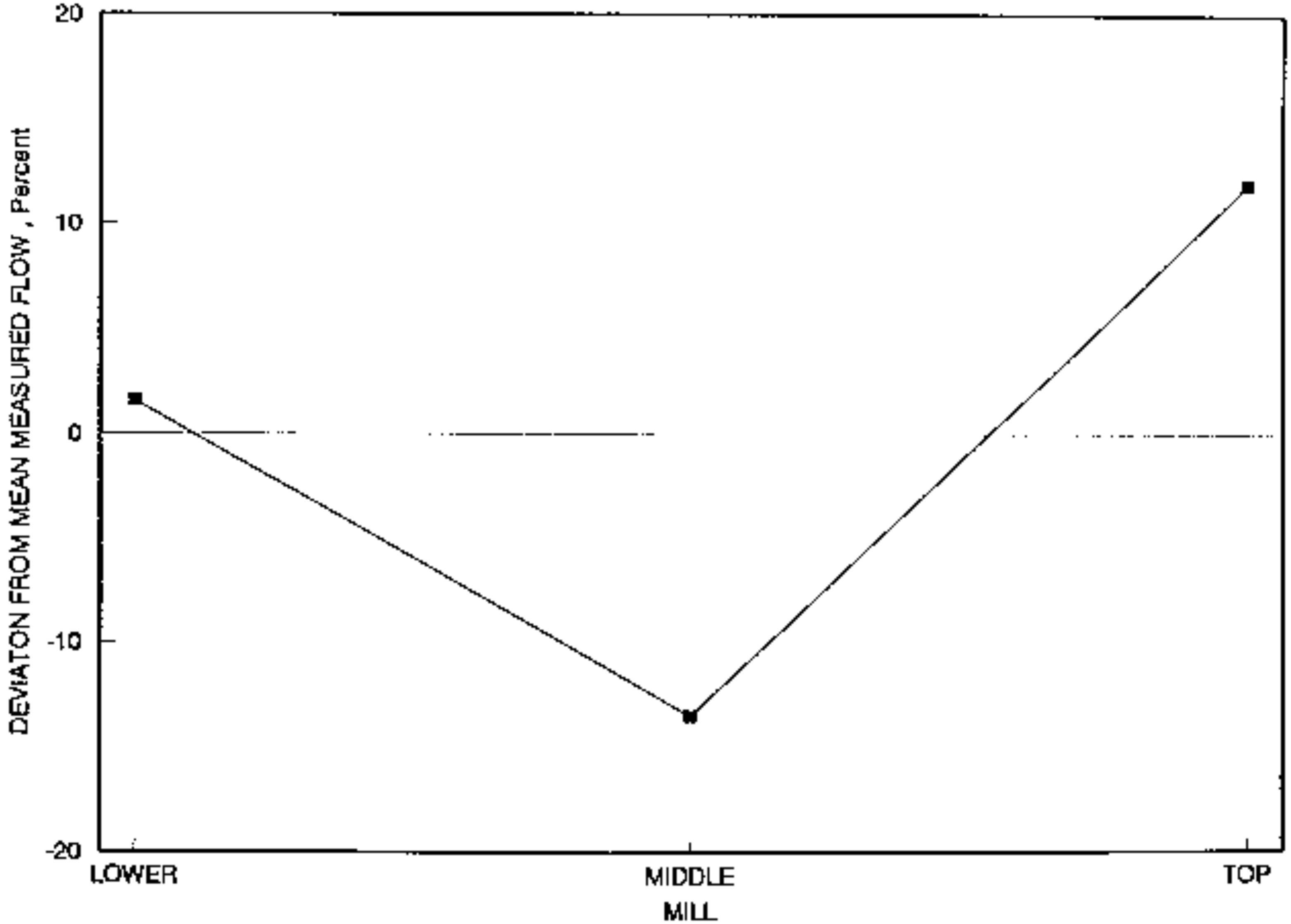
FIGURE 5-11 PHASE 3A MILL BIAS



E:\SCS\FREE\RHAM3B\FIG5-11.DRW

TABLE 5-7
COMBUSTION AIR FLOW DISTRIBUTION
HAMMOND UNIT 4 PHASE 3B - LNB + AOFA

TEST NO.	GROSS LOAD Mwe	OFA DAMPERS Pct OPEN F	OFA DAMPERS Pct OPEN R	ECON EXCESS O2 (DRY %)	AIR FLOW RATES SECONDARY lb/hr	PRIMARY l/hr	PRIMARY Percent of Total	OFA lb/hr	OFA Percent of Total
115	472	47/47	44/46	3.8	2,437,598	836,841	20.0	847,935	20.3
116	476	55/51	45/51	3.9	2,490,624	832,546	19.5	880,120	20.6
117	301	36/22	30/21	3.9	1,628,886	734,279	27.3	259.776	9.7
118	300	36/26	31/22	4.2	1,589,363	716,699	26.6	349,802	13.0
119	400	32/24	26/22	4.4	2,350,423	801,480	21.9	446,909	12.2
120	401	32/27	26/20	4.5	2,349,506	756,031	20.5	487,798	13.2

The coal samples were analyzed for proximate and ultimate composition, calorific value, grindability and ash fusion properties. Table 5-8 presents the results of these analyses, which show that the coal properties remained very consistent over the duration of the testing.

For the most part, the coal properties are consistent with the analyses obtained during the previous testing phases of the program. Several exceptions are with respect to the sulfur levels and the fixed carbon (FC) to volatile matter (VM) ratio. The sulfur levels averaged 1.67 percent during Phase 3B while they were 1.53 during Phase 3A. Similarly the FC/VM ratio was 1.50 for Phase 3B and 1.61 for Phase 3A.

Based upon limited data, the change in FC/VM between Phases 3A and 3B would indicate that with the same NOx control method (either LNB alone or LNB + AOFA) for both coals (Phase 3B and 3A coals), the Phase 3A coal would emit a higher level of NOx than the Phase 3B coal. This aspect of the differences in the coal could help to explain the apparent high NOx reduction of approximately 40 percent) between Phases 3A and 3B. This coal related factor coupled with the mill biasing discussed above points to the potential reason why the Phase 3B NOx levels were low and that this low level of NOx may not have been a result of burner adjustments. Information presented in the Phase 3A Interim Report show that burner adjustments provide relatively small changes in NOx levels for similar operating conditions. The two factors that influenced the NOx level most were excess oxygen and mill biasing in that order of the degree of influence. Burner adjustments showed NOx influences well below these two factors.

The results of the CEGRIT furnace ash and the furnace bottom ash analyses are shown in Table 5-9. As in the baseline testing (Phase 1), the CEGRIT LOI values were much higher than the bottom ash samples. This is to be expected since most of the unburned carbon will exit the furnace as fine particles rather than depositing on the walls and subsequently falling into the bottom hopper. Comparison of Tables 5-5 and 5-9 indicates that the CEGRIT LOI levels are much lower than the Method 17 levels. The CEGRIT samples are not collected isokinetically and may exclude a portion of the very small ash particles which may, in turn, represent most of the carbon/LOI content of the fly ash.

TABLE 5-8
HAMMOND UNIT 4 PERFORMANCE TEST COAL ANALYSIS
PHASE 2 - LNB + AOFA

TEST NO.	Ultimate Analyses, (%)								
	Date	H2O	C	H	N	Cl	S	Ash	O
115	06/17/93	6.16	72.22	4.67	1.32	0.02	1.58	8.69	5.36
	07/10/90	5.62	71.46	4.72	1.35	0.03	1.64	8.97	6.25
	07/10/90	6.36	71.48	4.64	1.40	0.06	1.67	9.05	5.40
116	06/18/93	6.81	69.92	4.63	1.34	0.03	1.69	9.74	5.87
	06/18/93	7.49	69.08	4.60	1.34	0.08	1.79	9.88	5.83
	06/18/93	6.71	70.73	4.60	1.40	0.06	1.82	9.86	4.88
117	06/19/93	7.10	69.95	4.66	1.38	0.05	1.72	9.93	5.25
	06/19/93	6.82	69.33	4.64	1.41	0.05	1.71	10.20	5.89
	06/19/93	7.04	69.38	4.61	1.40	0.03	1.72	10.06	5.79
118	06/20/93	6.59	69.05	4.66	1.42	0.02	1.96	10.20	6.12
	06/20/93	6.76	69.69	4.62	1.49	0.02	1.64	9.52	6.28
	06/20/93	7.08	69.46	4.65	1.43	0.03	1.75	9.92	5.71
119	06/21/93	6.27	71.13	4.68	1.37	0.05	1.56	9.49	5.51
	06/21/93	5.14	72.93	4.71	1.41	0.07	1.51	8.99	5.31
	06/21/93	5.68	72.35	4.76	1.44	0.07	1.57	8.99	5.21
120	06/22/93	5.95	71.57	4.64	1.36	0.04	1.54	9.18	5.76
	06/23/93	5.64	73.52	4.76	1.44	0.03	1.51	8.93	4.21
AVERAGE		6.42	70.78	4.66	1.39	0.04	1.67	9.51	5.57
STD		0.63	1.39	0.05	0.04	0.02	0.12	0.49	0.50
VAR		0.40	1.92	0.00	0.00	0.00	0.01	0.24	0.25

TABLE 5-9
HAMMOND UNIT 4 PERFORMANCE TEST
CEGRIT AND BOTTOM ASH LOI
PHASE 3B - LNB + AOFA

TEST NO.	DATE	NOMINAL LOAD MWe	ECON EXCESS O2 (%)	LOI, % CEGRIT EAST	LOI, % CEGRIT WEST	LOI, % BOTTOM ASH
115A	06/17/93	480	3.8	2.15	2.40	
115B	06/17/93	467	4.0	1.39	5.09	0.71
115C	06/17/93	462	3.9	2.35	3.74	
116A	06/18/93	476	3.9	1.57	3.20	
116B	06/18/93	472	3.8	2.21	4.66	0.13
117A	06/19/93	303	4.0	2.16	3.33	
117B	06/19/93	299	4.1	1.97	3.65	1.05
118A	06/20/93	302	4.3	1.94	2.92	
118B	06/20/93	298	4.3	2.11	3.36	0.03
119	06/21/93	400	4.5	2.58	5.76	0.33
120	06/22/93	401	4.5	2.69	5.30	0.93

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52.6 Boiler Efficiency

During the performance tests at each load point, measurements were recorded for the flue gas temperatures and gaseous species, both upstream and downstream of the air preheaters, using the DAS and the CEM, for the purpose of calculating the heat loss efficiency Over several hours of each test the in-situ O_2 probes upstream and downstream of the air preheaters were sampled continuously in sequence. In addition, the gas temperatures in each duct were measured continuously (every 5 seconds - compiled into 5-minute averages) over the entire test duration. Each efficiency test was approximately two hours in duration. CO measurements were obtained from composite sampling of the CEM at discrete intervals over the test duration.

ASME PTC 4.1 Heat Loss Method calculations were made of boiler efficiency losses for dry flue gas, moisture in flue gas (humidity plus moisture in fuel plus hydrogen combustion product), LOI in fly ash, LOI in bottom ash (negligible), and radiation loss (standard ASME curves). These calculations utilized boiler operating and coal/ash data discussed in the previous paragraphs. The results of the efficiency calculations are presented in Table 5-10.

TABLE 5-10

HAMMOND UNIT 2 ASME PTC 4.1 BOILER EFFICIENCY

TEST No.	DATE	AVERAGE LOAD Mwe	MEASURED EFFICIENCY, percent	NORMALIZED EFFICIENCY, percent
115	6/17/93	472	89.142	89.083
117	6/18/93	301	89.480	89.351
119	6/21/93	400	89.268	89.315

The efficiencies are determined for "as measured" conditions and for "design" air preheater temperature conditions (normalized). The purpose of the boiler efficiency calculations is to document the Phase 3B boiler efficiencies at specific operating conditions for comparison to the efficiencies determined in other test phases. Thus, the important parameter is any change in efficiency attributable to the LNB and AOFA retrofits, rather than the absolute value of efficiency measured. For this reason, some efficiency loss components not related to combustion (e.g. blowdown,, steam properties, etc.) were not considered. However, the heat loss calculations were done based upon the measured calorific value, moisture and chemical composition of the as-fired fuel samples.

5.3 Verification Tests

A short series of verification tests were conducted to ascertain whether any significant changes had occurred in the Hammond Unit 4 NOx emission characteristics during the long-term testing which might influence the long-term data analysis. Table 5-11 summarizes the results of those tests. As observed during the diagnostic testing (Sect 5.1), the Unit 4 ESP could not accommodate high load operation on a regular basis without producing excessive opacity emissions. For that reason the high load testing which could be achieved during the verification phase was substantially restricted. Also, because of system load demands, testing at loads below 300 MWe was not possible. Therefore, most of the verification test results were obtained at 300 to 400 MWe. These data points are included in the diagnostic test plots of NOx vs. O_2 (Figures 5-3 through 5-6). It can be seen that the NOx emissions during the verification testing were comparable to the earlier emission levels under comparable operating conditions. It is therefore concluded that no fundamental changes occurred in the unit emission characteristics during the long-term testing.

TABLE 5 - 11

SUMMARY OF HAMMOND UNIT 4 PHASE 3B VERIFICATION TESTING

TEST NO.	DATE	TEST CONDITIONS	LOAD MWe	MOOS PATTERN	OFA FLOW (KPPH)	DAS O2 DRY (%)	NOx AT 3% O2 (lb/mmBtu)
123-1	08/09/93	VERIFICATION - NOM O2 300 MWe	301	B	304	4.3	0.353
123-2	08/10/93	- HIGH 02	298	B	318	5.3	0.398
123-3	08/10-93	- LOW O2	304	B	311	3.8	0.329
123-4	08/10/93	- NOM O2	304	B	312	4.2	0.348
123-5	08/10/93	- NOM O2 MILL VARIATION	304	B,D	316	4.4	0.358
124-1	08/10/93	VERIFICATION - NOM O2 400 MWe	384	B	307	4.7	0.382
125-1	08/24/93	VERIFICATION - HIGH O2 NOM OFA	397	B	319	5.1	0.437
125-2	08/25/93	VERIFICATION - LOW O2 NOM OFA	393	B	283	3.8	0.357
125-3	08/25/93	VERIFICATION - NOM O2 NOM OFA	393	B	300	4.5	0.401
125-4	08/25/93	VERIFICATION - NOM O2 NOM OFA	394	B	417	4.7	0.384
125-5	08/25/93	VERIFICATION - NOM O2 NOM OFA	393	B	230	4.6	0.414
126-1	8/26/93	FULL LOAD VERIFICATION, NOMINAL O2/OFA	480	AMIS	870	4.1	0.417

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6.0 LONG-TERM DATA ANALYSIS

The long-term testing consisted of continuous measurement of operating parameters while the unit was under load dispatch control. This long-term testing was performed from May 11, 1993 through August 13, 1993. During this period unit outages were experienced that resulted in some lost days of data capture. The data capture was, however, sufficient to fully characterize the unit both from an engineering perspective as well as a regulatory point of view.

The focus of the analysis of this long-term data was;

1) Characterization of the daily load and NOx emissions and the within day statistics,

2) Characterization of the NOx emissions as a function of the O_2 and mill patterns for all five-minute CEMS data,

3) Determination of the thirty-day rolling average NOx emissions based upon valid days and hours of CEMS data,

4) Determination of the achievable NOx emission level based upon valid days of CEMS data.

and 5) Comparison of long-term results to short-term results.

The following paragraphs describe the major results of these analyses.

6.1 Unit Operating Characteristics

Figures 6-1 and 6-2 illustrates the histogram for NOx emissions and the load experienced during the Phase 3B long-term test period. From Figure 6-1, it can be seen that the five-minute average NOx emissions generally varied from approximately 0.26 to 0.64

FIGURE 6-1 PHASE 3B HOURLY AVERAGE CHARACTERISTICS

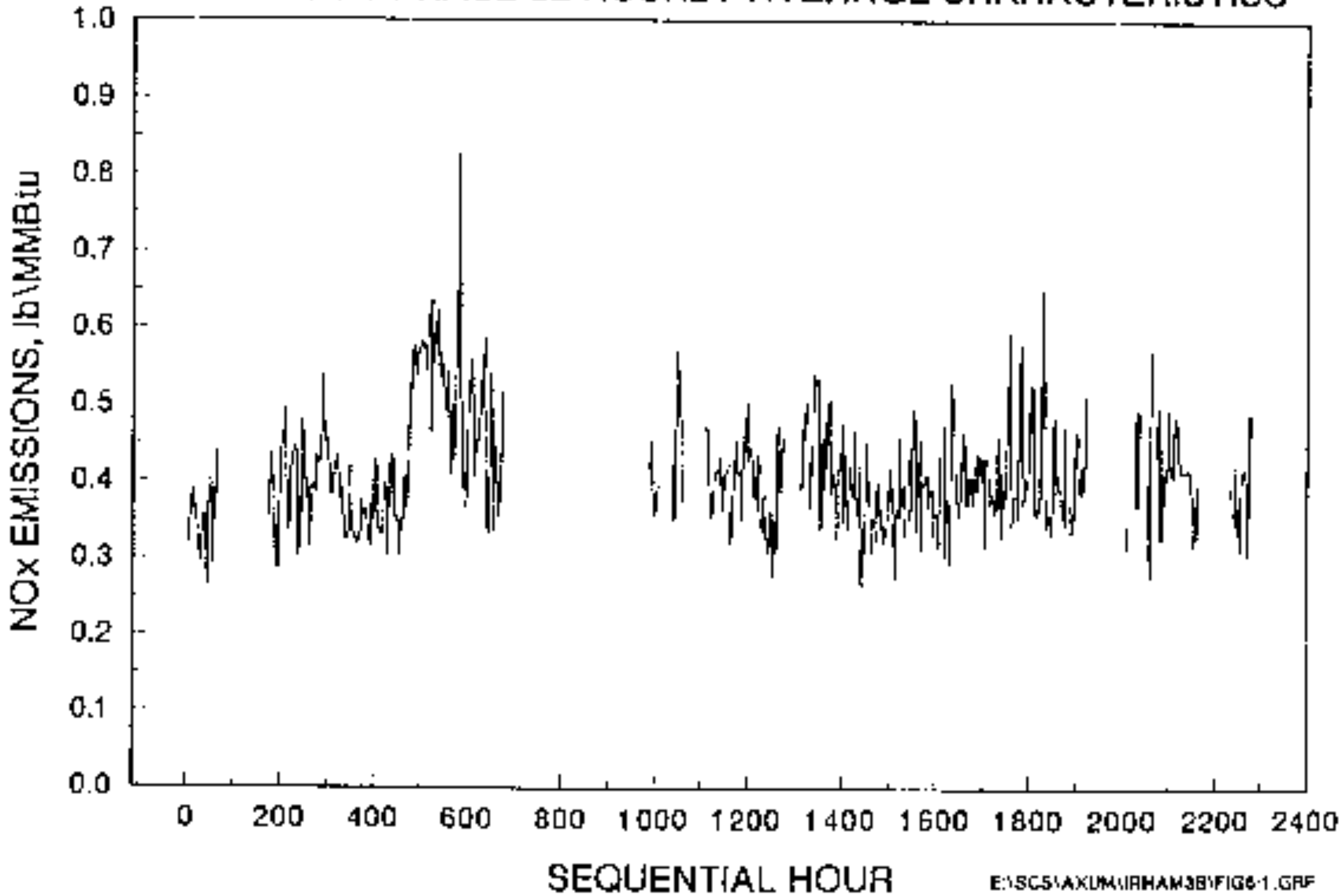
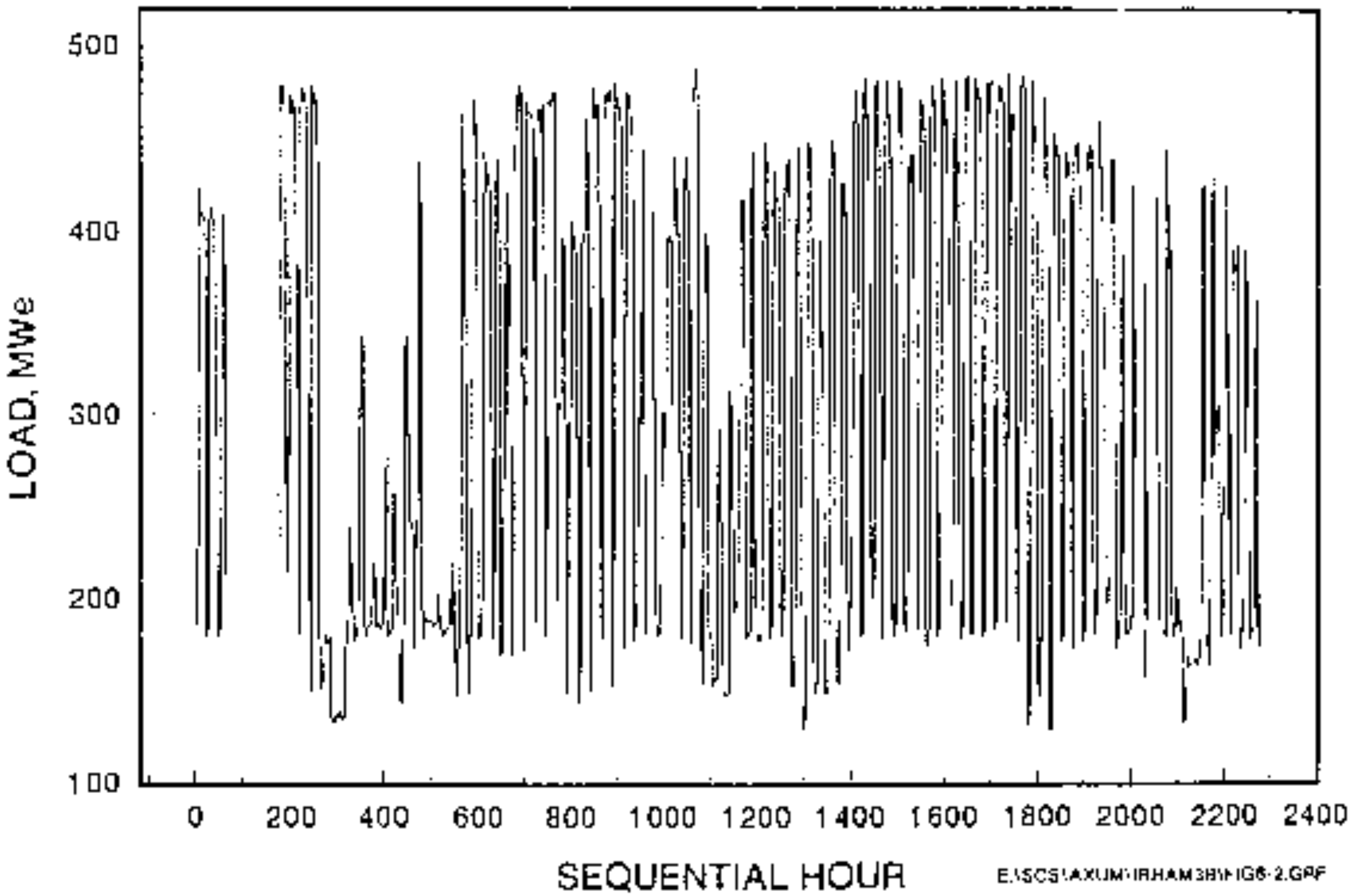


FIGURE 6-2 PHASE 3B HOURLY AVERAGE CHARACTERISTICS



lb/10^6 Btu from low- to high-load. It is difficult to determine a trend using this type of data. The data shown in Figure 6-2 does however illustrate that the unit experienced load changes from the minimum operating load (180 MWe) to the maximum continuous operating load (480 MWe) during the entire long-term test period. In addition, it is evident from Figure 6-2 that there were periods of time early in the long-term testing that the unit did not operate over 300 MWe.

From the data for the long-term testing (May 11 through August 13, 1993), the daily averages of load and NOx were determined arid are shown in Figure 6-3. These daily average data were determined using the EPA criteria for valid data explained in Section 4.2.1. Only days with at least 18 hours of data are presented in this figure. For the Phase 3B long-term test period, the daily average emissions ranged from approximately 0.32 to 0.58 Ib/MMBtu.

One method of characterizing the boiler operating characteristics during the long-term testing is to examine the within-day variation of load and NOx. This was accomplished by segregating the data by hour of the day, i.e., 0100, 0200,...2400. For these segregated data, the mean load and NOx were computed. In addition, the hourly values representing the lower 5 percent and upper 95 percent of all values were determined. Typical results of this type of analysis are shown in Figure 64. Typical results from previous phases of the program illustrated that the daily trend for load was representative of a base loaded unit. These data shown in Figure 6-4 indicate that the unit continued to operate as a base loaded unit for the most part but spent less time at the maximum and NOx emissions over the entire long-term test period than during Phases 1 and 2. The figure illustrates that the unit was operated as a base loaded unit for most of the day (on average 12 hours were above 300 MWe). This is a considerably lower base load than experienced during the Phases 1 and 2 but greater than that experienced during Phase 3A. It is evident that the NOx versus load characteristics are very flat with respect to load change. The exact relationship will be illustrated in the following paragraphs.

FIGURE 6-3 DAILY AVERAGE CHARACTERISTICS

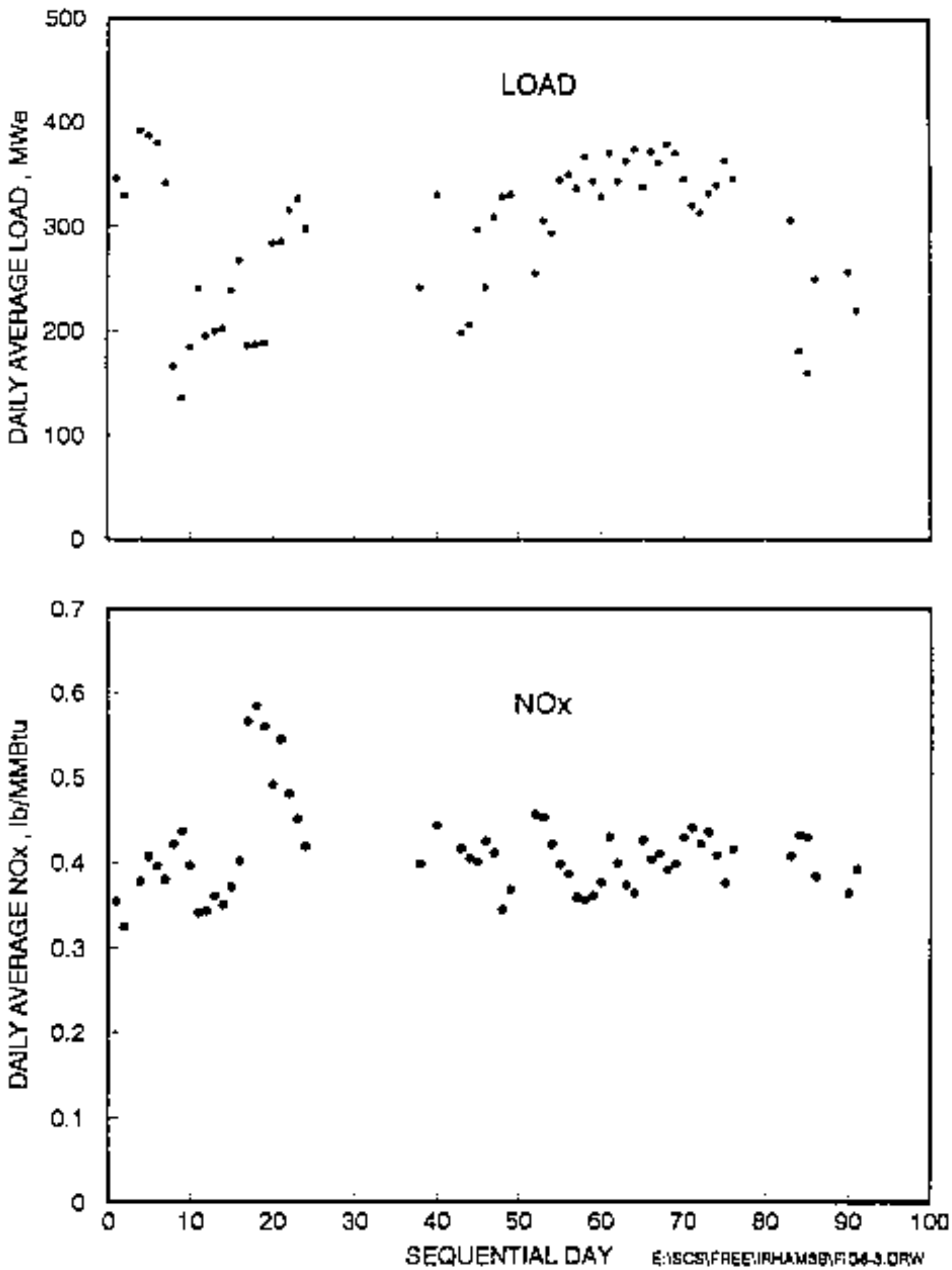
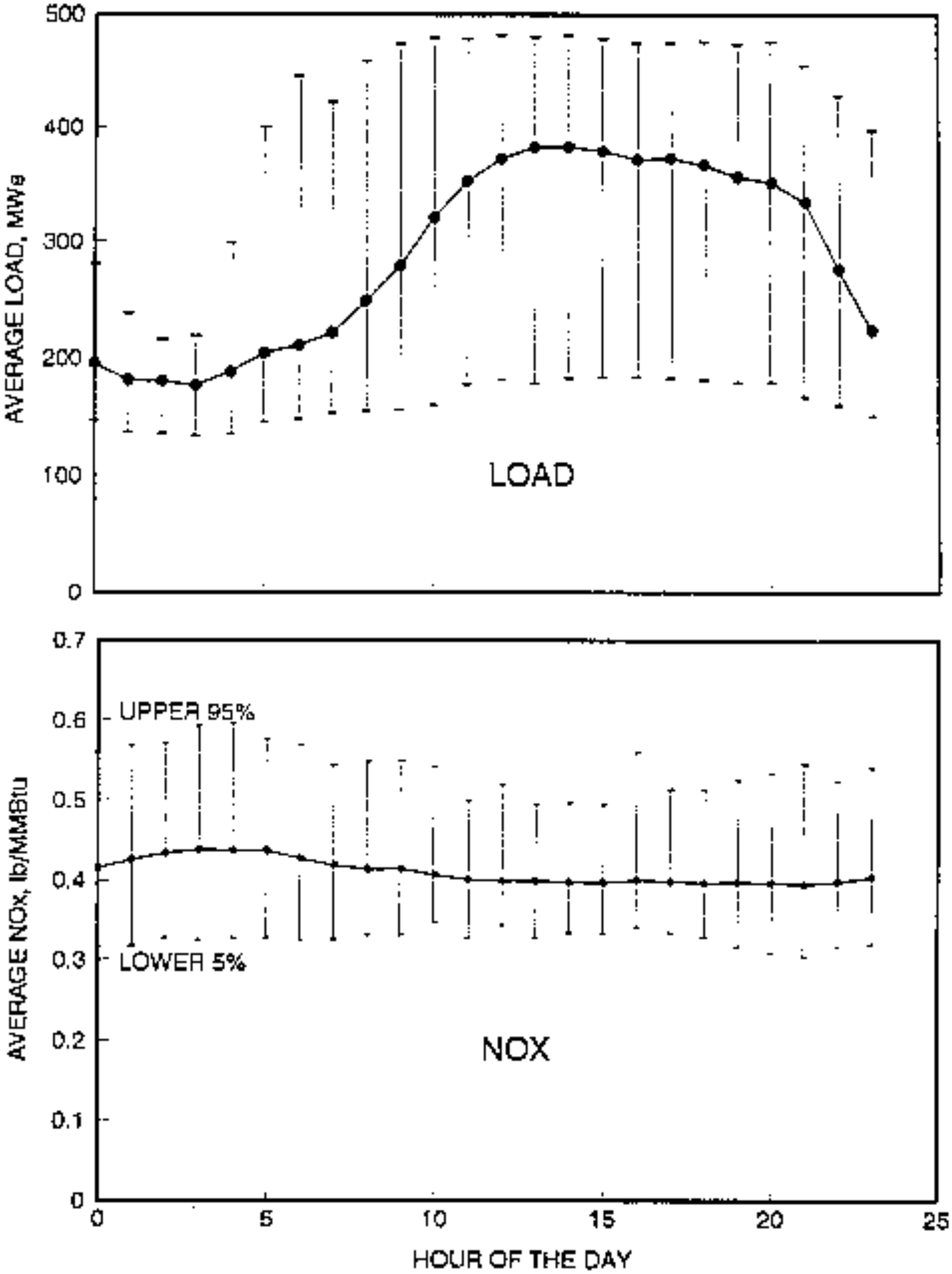


FIGURE 6-4 DIURNAL CHARACTERISTICS



E:\SCS\FREE\IRHAMS9\FIG6-4.DRW

6.2 Parametric Test Results

For the parametric analyses, all of the valid five-minute data were used. The 5-minute and hourly average emission data were analyzed to determine the overall relationship between NOx and load and the effect of boiler O_2 on NOx emissions for certain frequently used mill patterns. Since these data were obtained while the unit was under normal load dispatch control, they represent the long-term NOx characteristics.

The NOx versus load relationship was determined by first segregating the 5-minute average load data into 20 MWe wide load ranges. Table 6-1 provides the results for this segregation of the data for the entire long-term data set. The population for each load

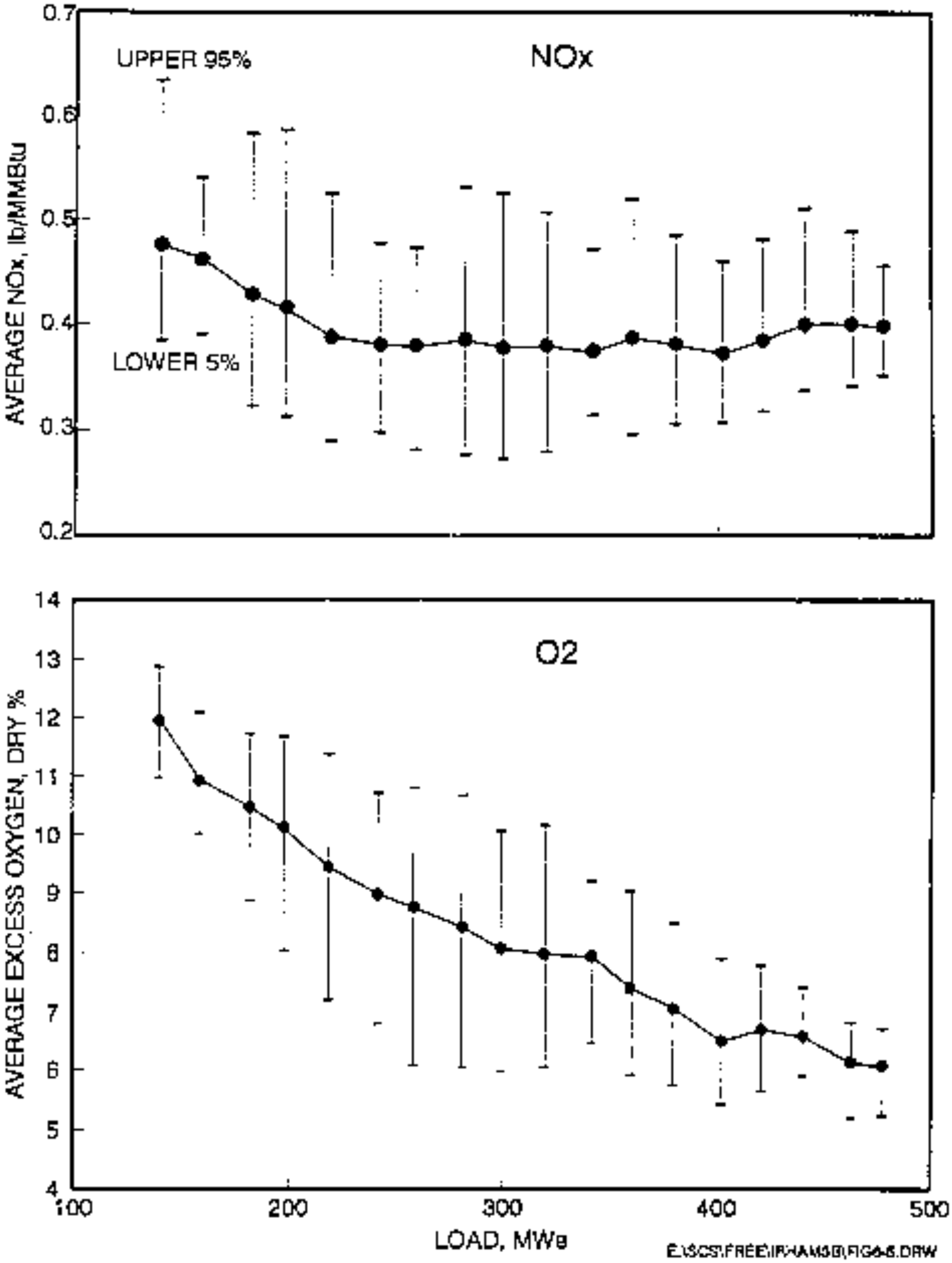
range, as well as the lower five percentile and upper ninety-five percentile are shown for both load and NOx emission values. Figure 6-5 illustrates the NOx and excess oxygen versus load trend for these data. This figure illustrates that the NOx remained relatively constant from the 500 MWe down to the 200 MWe load points at an emission level of approximately 0.40 lb/MMBtu. At loads below this point, the AOFA was essentially closed and the NOx emissions increased with decreasing load up to approximately 0.48 lb/MMBtu. The excess downstream of the air preheater shows the same trend as that for the other phases of the program - increasing excess oxygen with decreasing load.

The effect of operating O_2 on NOx emissions for certain mill patterns was examined for load ranges that corresponded to some of the loads tested during the short-term test portion of the Phase 2 test effort. These ranges were the 180-190, 290-300 390400 and 470 480 MWe ranges. All of the valid five-minute data for these load ranges were used to assess the impact of excess oxygen level for the most commonly used mill patterns. In order to determine the most frequently used patterns the frequency distribution of the mills-in-service pattern was determined. Table 6-2 presents the frequency distribution for the two most used mill patterns. It is apparent that there are certain preferred mill patterns for each load range. These patterns are dictated by the operational requirements of the unit (i.e., slag minimization, steam temperature control, etc.). Prior to commencing the short-term testing effort, discussions with plant operations indicated that certain mill patterns were the preferred patterns. These patterns were then used during the diagnostic and performance testing with the intent of comparing the results with the same patterns during long-term testing. The mill patterns used during the short-

TABLE 6-1 PHASE 3B LNB + OFA LONG - TERM TEST STATISTICS

LOAD CATEGORY (MWe)	SAMPLE SIZE	LOAD (MWe)			EXCESS OXYGEN (%DRY)			NOx (LB/MMBTU)		
		LOWER 5%	AVERAGE	UPPER 95%	LOWER 5%	AVERAGE	UPPER 95%	LOWER 5%	AVERAGE	UPPER 95%
125-150	1040	131	140	149	11.0	12.0	12.9	0.385	.0476	0.635
150-170	1174	151	159	168	10.0	10.9	12.1	0.390	0.462	0.541
170-190	4881	175	182	188	8.9	10.5	11.7	0.323	0.428	0.582
190-210	1080	190	198	208	8.0	10.1	11.7	0.313	0.416	0.586
210-230	642	211	219	227	7.2	9.5	11.4	0.290	0.387	0.526
230-250	550	232	241	249	6.8	9.0	10.7	0.298	0.381	0.478
250-270	448	251	258	269	6.1	8.8	10.8	0.281	0.379	0.473
270-290	341	272	281	289	6.0	8.4	10.7	0.277	0.386	0.531
290-310	476	291	299	308	6.0	8.1	10.1	0.273	0.377	0.525
310-330	239	311	320	329	6.0	8.0	10.2	0.280	0.379	0.507
330-350	494	332	341	348	6.5	7.9	9.2	0.314	0.375	0.472
350-370	279	351	360	369	5.9	7.4	9.0	0.296	0.387	0.520
370-390	414	371	380	389	5.7	7.1	8.5	0.306	0.381	0.485
390-410	733	391	402	409	5.4	6.5	7.9	0.307	0.372	0.460
410-430	1184	411	421	429	5.6	6.7	7.8	0.318	0.385	0.480
430-450	1389	431	440	449	5.9	6.6	7.4	0.337	0.400	0.511
450-470	1251	452	462	469	5.2	6,.2	6.8	0.341	0.400	0.489
470-490	1527	471	477	485	5.2	6.1	6.7	0.352	0.398	0.456
490-510	8	491	494	500	5.9	6.3	6.6	0.374	0.398	0.441

FIGURE 6-5 LOAD CHARACTERISTICS



term test effort were the E-, B&E, B&C and E&F-MOOS at loads below 400 MWe. Referring to Table 6-2 it is evident that these patterns were not the most prevalent during this long-term test effort due to a desire limit the use of the old mills. As a consequence of this, comparisons will not be presented between the short - and long-term results for this phase of the program.

TABLE 6-2
MILL PATTERN USE FREQUENCY

AVERAGE LOAD Mwe	MOOS	SAMPLE SIZE	AVERAGE O2%	AVERAGE Nox lb/MMBtu
186	B,E	1070	9.6	0.69
186	C,F	379	9.2	0.63
296	B,E	1180	8.4	0.51
296	B,C	834	9.0	0.44
396	E	717	7.3	0.61
396	F	307	7.1	0.48
474	NONE	142	6.6	0.64

6.3 Thirty-day Rolling Averages

The NSPS Subpart Da and Db standards are based upon compliance on a thirty-day rolling average. While this unit is not required to comply with these standards, it is of some value to evaluate the data for Phase 3A on a thirty-day rolling average basis and later compare it to the results from previous and subsequent phases of the program. Thirty-day rolling average load, NOx, and O_2 were computed using the valid hourly data as defined by the EPA criteria explained in Section 4.2.2. These thirty-day rolling averages are shown in Figure 6-6 for the 87 (56 rolling averages) boiler operating days (by EPA criteria) of data.

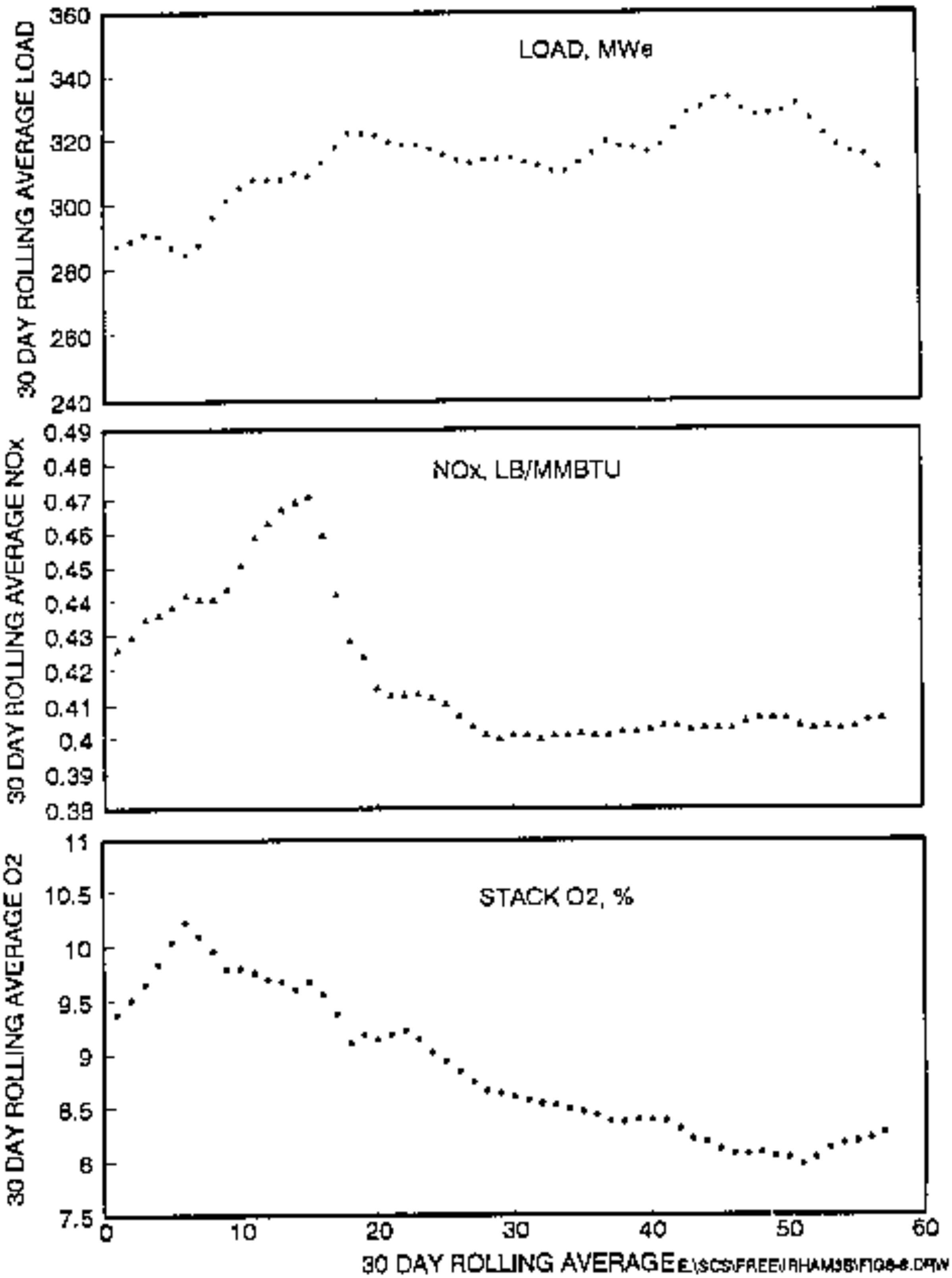
The thirty-day rolling average results shown in Figure 6-9 are only representative of the load scenario that was experienced by the unit during this long-term test period. During other periods when the load might be significantly different, the rolling averages would be expected to be somewhat different. For this particular period, it can be seen that the 30-day rolling average load was generally in the 320 to 340 MWe range. Over the entire daily long-term effort there was a slight increase in the daily load. In the final report, thirty-day rolling average values will be computed for a consistent synthesized load scenario. These synthesized results will be used to illustrate the NOx emissions (and reductions) that would be reported on a unit if it were required to comply on a thirty-day rolling average basis standard.

6.4 Achievable Emission Characterization

EPA in their rulemaking process establishes an achievable emission level based upon daily average data samples obtained from CEMs. Most of this data is from NSPS Subpart Da units or units that used CEMs to obtain data during demonstration programs. The achievable NOx emission limit on a 3-day rolling average basis is determined using the descriptive statistics for 24-hour average NOx emissions. As discussed in Section 4.2.2, the SAS UNIVARIATE and AUTOREG procedures are used to determine the descriptive statistics for the 24-hour average NOx emissions data.

The results of the UNIVARIATE and AUTOREG analyses of the 24-hour average NOx emissions are presented in Table 6-3. The UNIVARIATE analysis indicated that the

FIGURE 6-6 30 DAY ROLLING AVERAGE CHARACTERISTICS



daily emissions were normally distributed. The AUTOREG analysis also indicated that the day-to-day fluctuations in NOx emissions followed a simple first order autoregressive model.

TABLE 6-3

DESCRIPTIVE STATISTICS FOR DAILY AVERAGE Nox EMISSIONS

Number of Daily Values	63
Average Emissions, (lb/MMBtu)	0.41
Relative Standard Deviaiotn, Percent	12.9
Distribution (Box-Cox Transformed)	Normal
First Order autocorrelation r	0.688

Based upon the EPA criteria, the achievable NOx emission limit should only be exceeded, on average, once per 10 years on a 30-day rolling average basis. The achievable emission depends on the long-term mean, variability, and autocorrelation level shown in Table 6-3. The achievable emission limit is computed using these values as discussed in Section 4.2.2. Based on the daily values given in Table 6-3 the 30-day and annual average NOx emissions were calculated. The 30-day average achievable emission level was estimated to be 0.51 lb/MMBtu. The annual average achievable NOx emission level was estimated to be 0.42 Ib/MMBtu. The assumption related to these achievable emission levels is that the Hammond unit will be operated in the future under similar load dispatching as that during the baseline test phase. As explained above under other load scenarios, the thirty-day rolling averages would be different and therefore the achievable emission level would also be different.

It should be noted that the mean, variability, and autocorrelation levels given in Table 6-3 are only estimates. There is an uncertainty level implicit in the estimates of each of these statistical parameters. The uncertainty level in the mean is dependent on the variability. The estimated variability is, to some extent, dependent on the level of autocorrelation. Thus, uncertainty levels in the descriptive statistics are linked.

6.5 Comparison of Phase 3A Long- and Short-Term Data

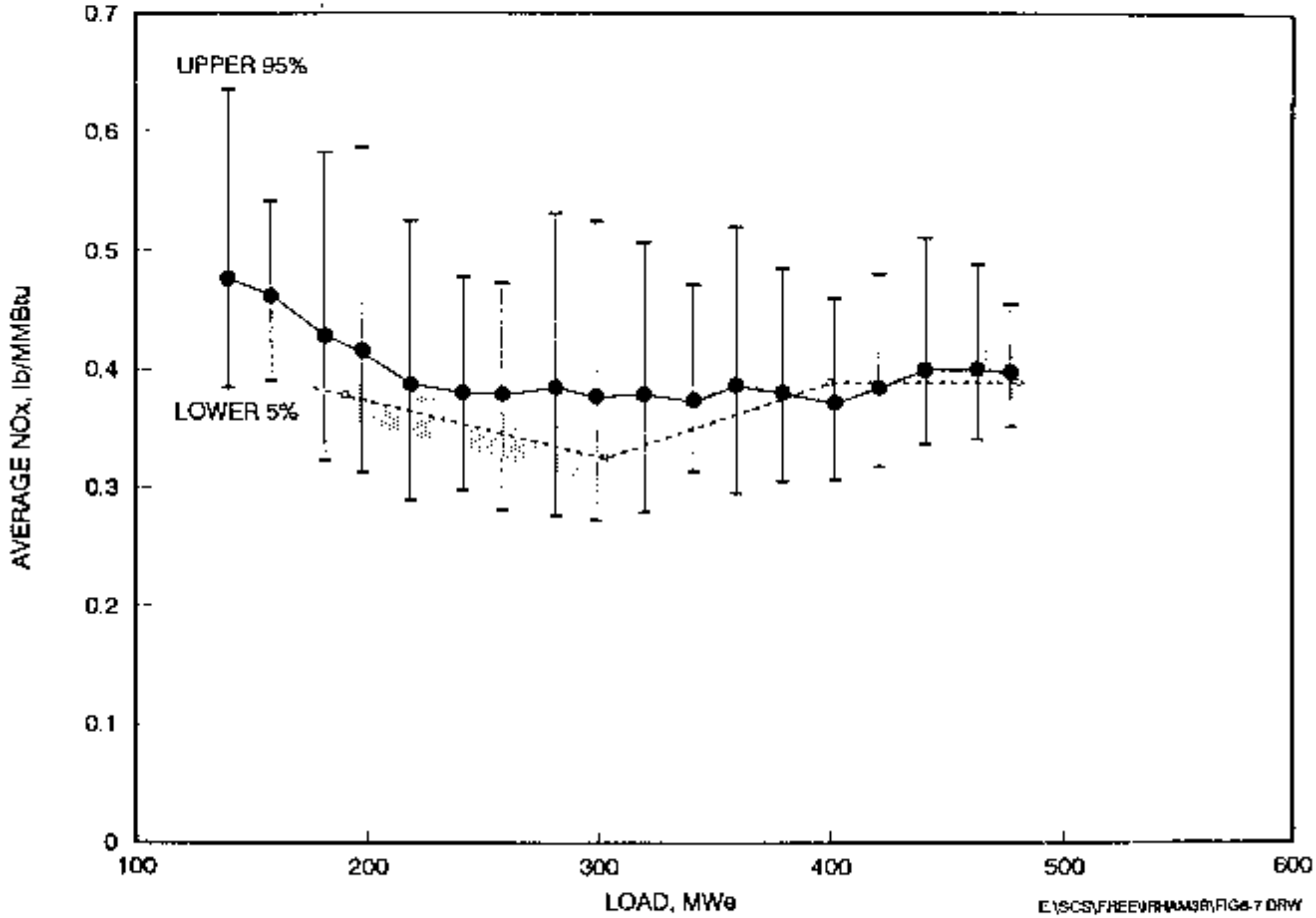
6.5.1 Long-Term NOx Data

Section 5.1 presented data for the load characteristics (See Figure 5-2). This data included a number of mill configurations and a range of excess oxygen levels. Similar data was collected during the long-term effort and is shown in Figure 6-5. The data in Figure 6-5 includes all of the configurations normally experienced during the period from late October 1990 through mid-March 1991. Figure 6-7 provides a comparison between these two sets of data showing the percentile interval (upper 95 percent and lower 5 percent) for the long-term data. From the comparison it is evident that the data obtained during the short-term efforts was, in many cases, within the upper 95 and lower 5 percent range. It is difficult to say if the same outcome would occur if the mix of configurations used in the short-term effort were the same as that experienced during the long-term effort. Nevertheless, the agreement between short-term and long-term data is much better than for either of the other two previous phase.

6.5.2 Comparison of Phase 1 and Phase 3A Long-Term NOx Results.

The true measure of the effectiveness of the particular NOx control technique is represented by the long-term load characteristics. A useful engineering comparison can be made by comparing the mean value of the baseline and the retrofit load characteristics. Figure 6-8 illustrates the load characteristics for the four configurations tested in this program. At the top load the LNB plus AOFA retrofit resulted in approximately 67 percent reduction in NOx from the Baseline configuration. Figure 6-9 shows that the effectiveness was generally between 57 and 67 percent over the useful load range. In the high load range, the effectiveness was generally in the upper 60 percent range.

FIGURE 6-7 COMPARISON OF LONG- AND SHORT-TERM NOx DATA
MEDIUM TO HIGH LOADS, ALL EXCESS OXYGEN LEVELS



E:\SCS\FREE\RHAM38\FIG6-7.DRW

FIGURE 6-8   COMPARISON OF LONG-TERM NOx DATA

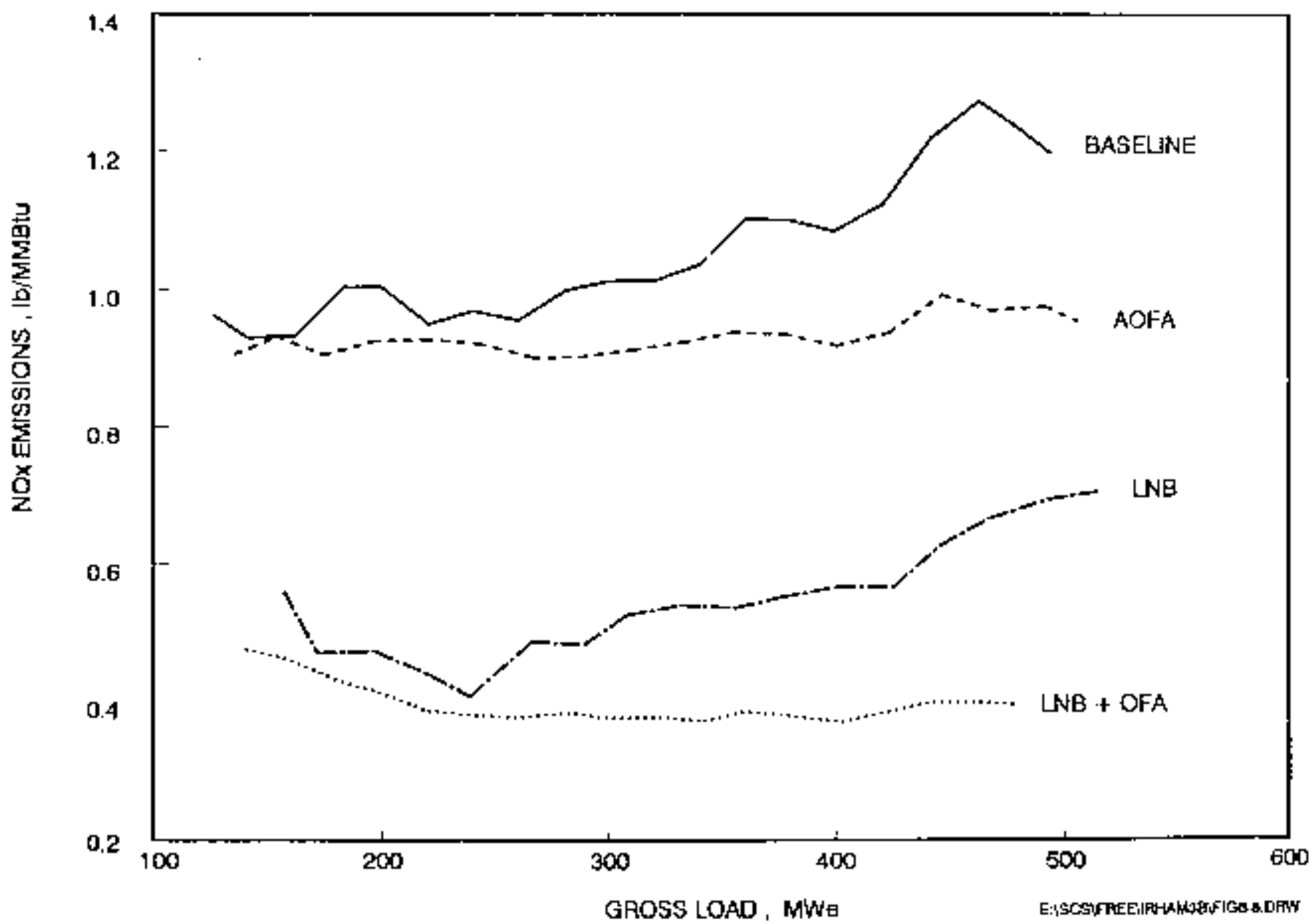


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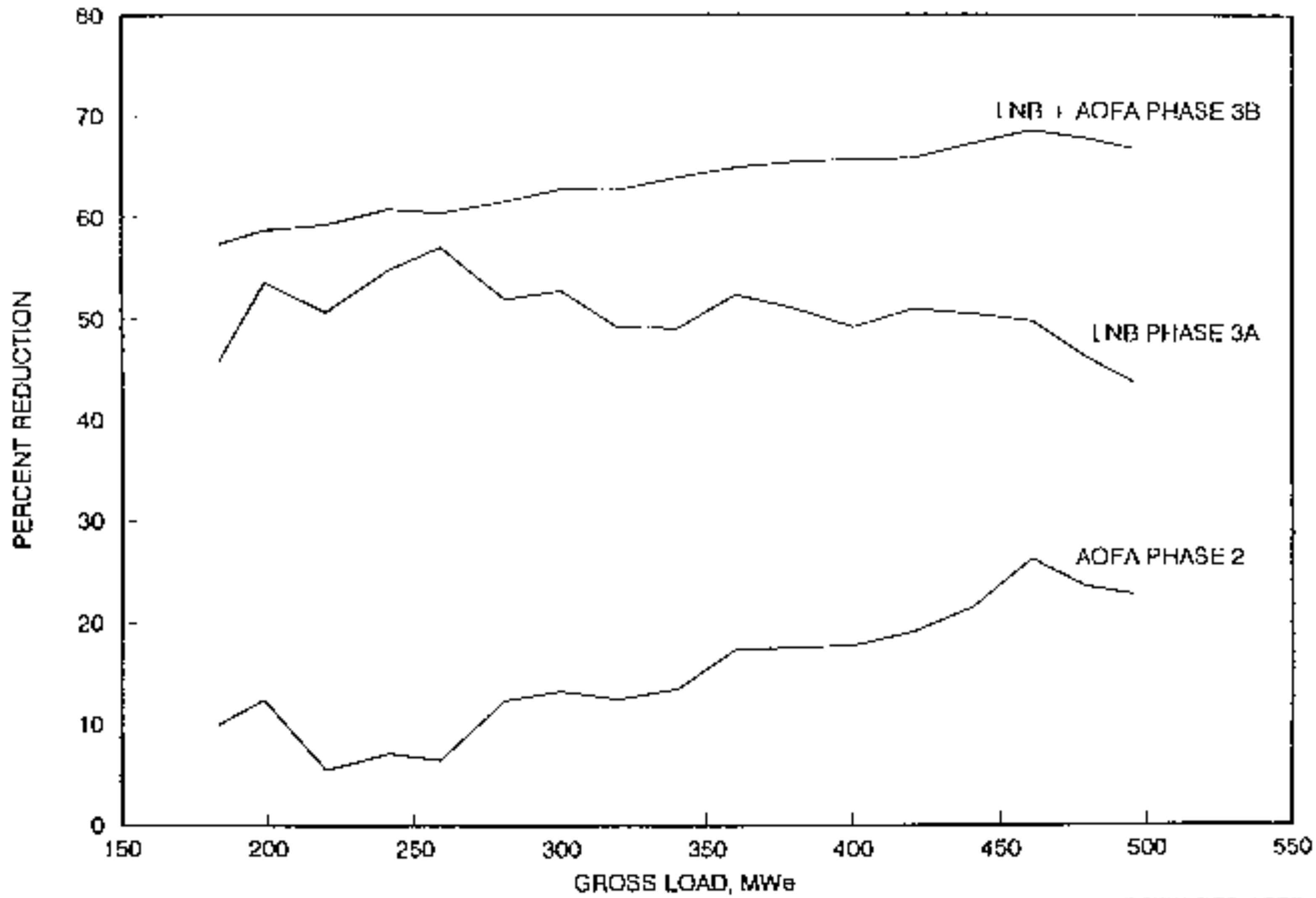
FIGURE 6-9 COMPARISON OF NOx CONTROL TECHNOLOGY EFFECTIVENESS



E:\SCS\HE\FURHAM3B\FIG6-9.DRW

Comparing the Phase 3B (LNB + AOFA) and Phase 3A (LNB) long-term NOx data should allow an estimate of the effectiveness of the AOFA as would the comparison of the Phase 1 (Baseline) and Phase 2 (AOFA) NOx levels. As was pointed out in Section 5.1.2 the short-term controlled tests showed that the AOFA retrofit (Phase 2) resulted in a full-load control effectiveness of 21.5 percent over the baseline configuration while the LNB plus AOFA (Phase 3B) retrofit resulted in a 16.3 percent full-load control effectiveness over the LNB configurations (Phase 3A). Examination of Figure 6-9 shows that the comparison of Phases 3A and 3B indicated an apparent control effectiveness of AOFA in excess of 40 percent. This is more clearly illustrated in Figure 6-10. As explained in Sections 5.2.4 and 5.2.5, a possible explanation of this anomaly is related to the inadvertent mill biasing in Phase 3B and the fixed carbon to volatile matter ratio producing lower NOx emissions during Phase 3B. Supporting long-term data will be presented in the following section.

6.5.3 Long-Term Operating Data

Excess Oxygen

During each phase of the program the excess oxygen levels were measured continuously at the exit of the air preheater. These data are somewhat compromised by the fact that leakage past the APH effects the relative readings. Additionally, leakage in the furnace backpass also affects the relative readings. Notwithstanding these factors, it is useful to show the trends of the excess oxygen levels for the various retrofit configurations. Figure 6-11 shows the long-term load characteristics of the excess oxygen. Due to the varying condition of the APH seals and the backpass leakage, it is difficult to establish if one retrofit configuration operated at higher or lower excess oxygen levels than others. It is clear, however, that the baseline configuration was operated at much lower levels than the retrofit configurations.

Mill Operation

Based upon the data presented in Section 5.2.4, it was apparent that an inadvertent bias was used for the performance tests during Phase 3B. It is presumed that this bias persisted throughout the long-term portion of Phase 3B. Figure 6-12 (a, b & c)

FIGURE 6-10 COMPARISON OF AOFA RETROFIT EFFECTIVENESS

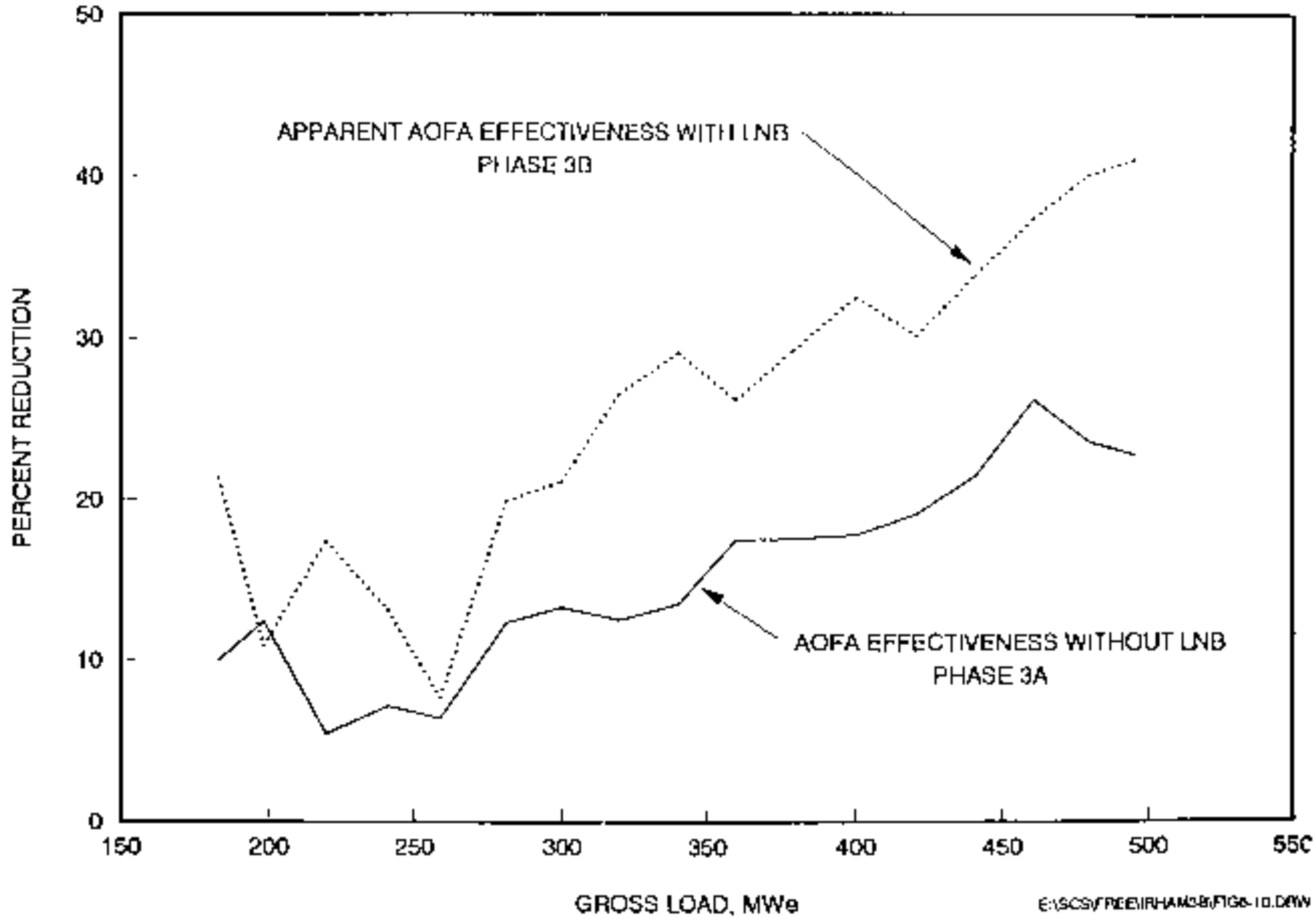


FIGURE 6-11 LONG-TERM EXCESS OXYGEN COMPARISON

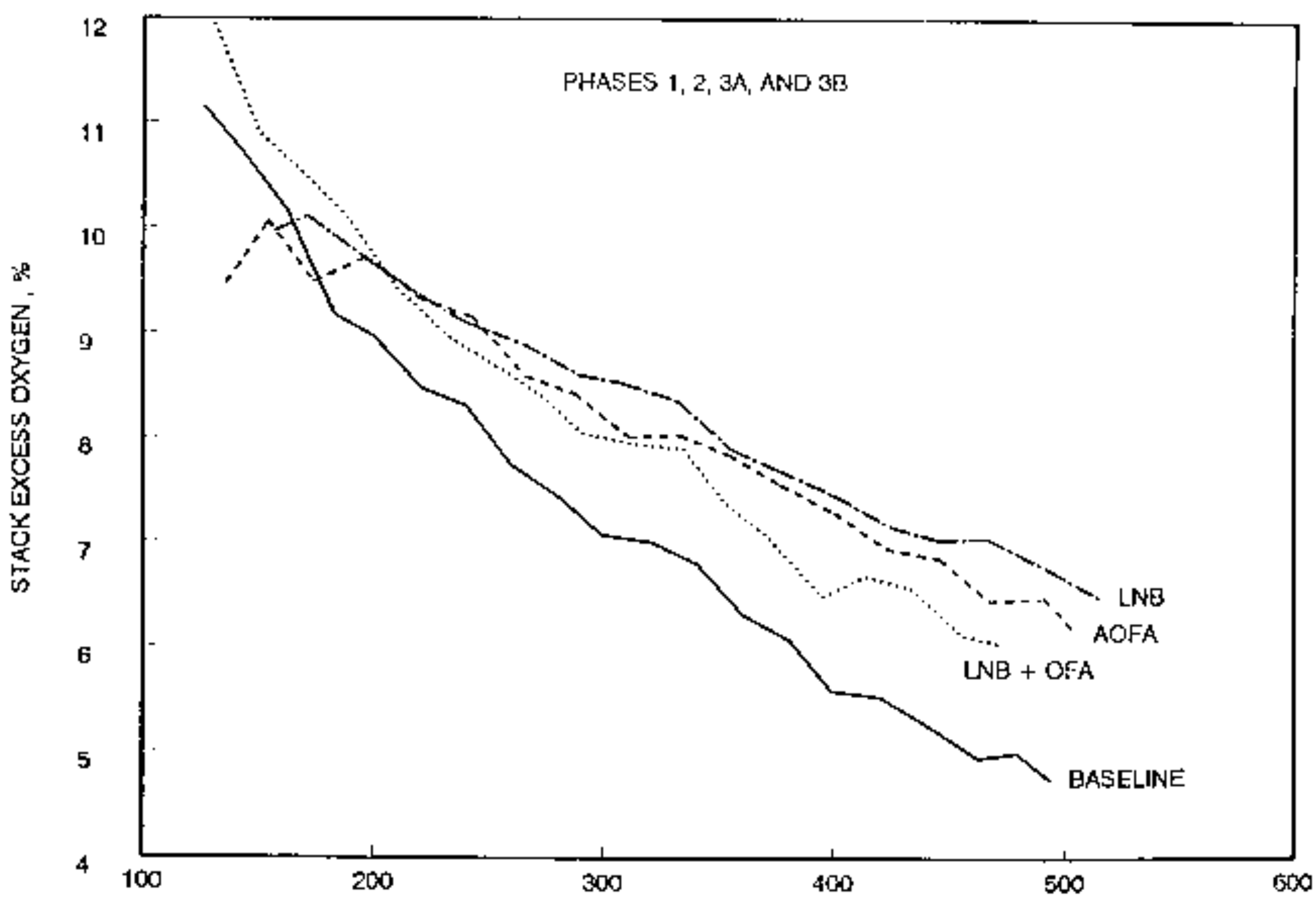


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FIGURE 6-12a PHASE 3B LONG-TERM MILL COAL FLOW
TOP MILLS C AND F

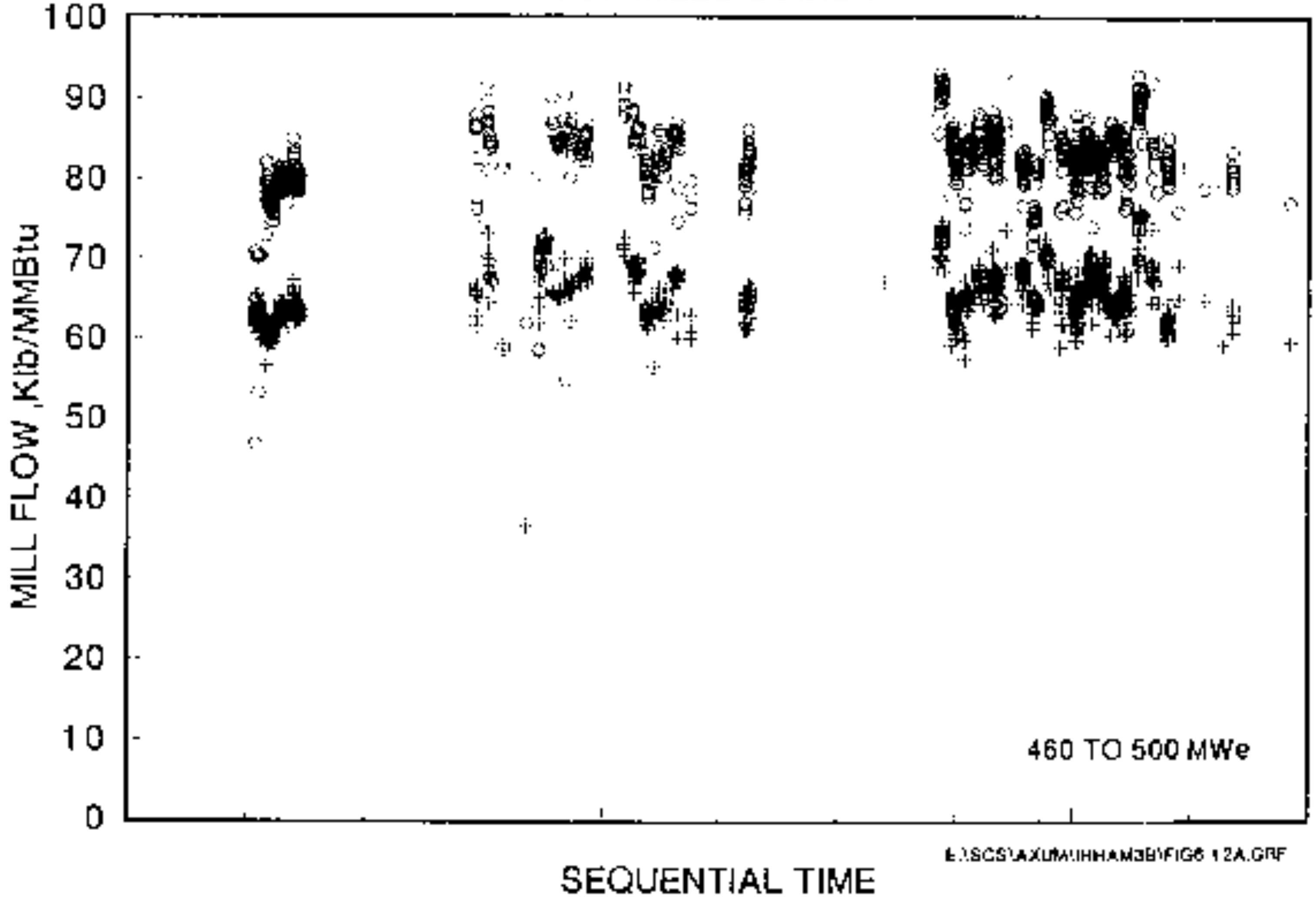


FIGURE 6-12b PHASE 3B LONG-TERM MILL COAL FLOW
CENTER MILLS D AND A

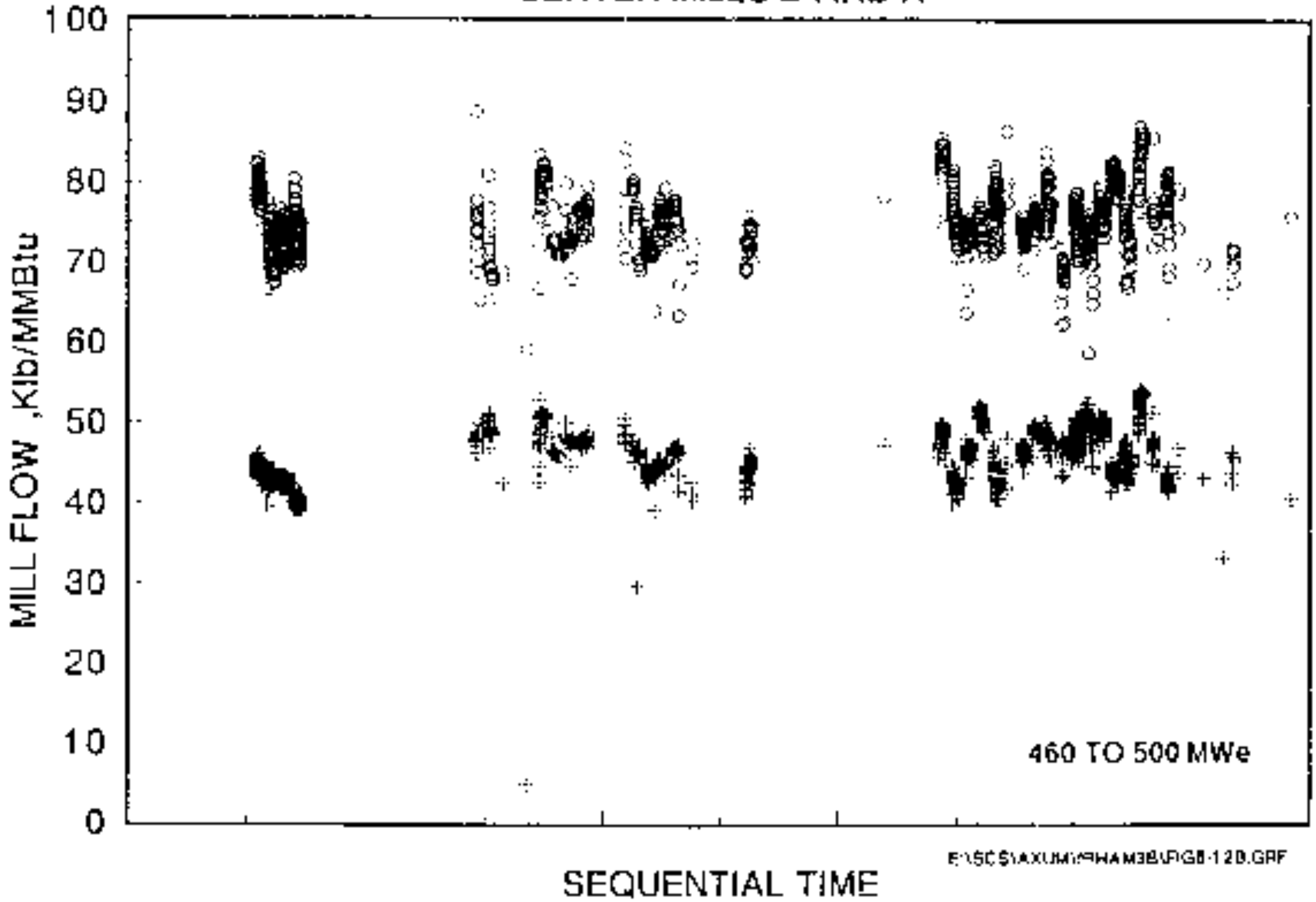
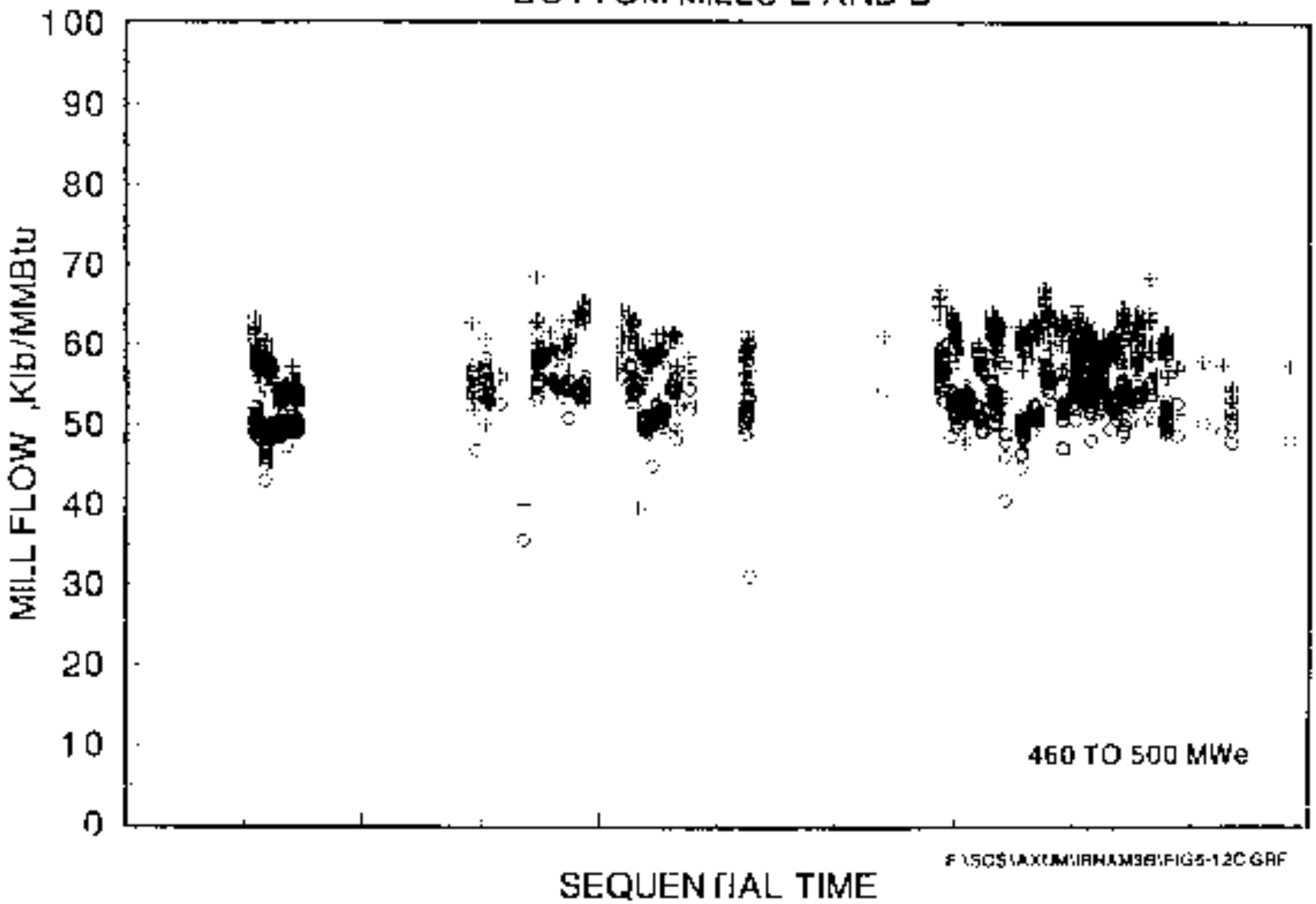


FIGURE 6-12c PHASE 3B LONG-TERM MILL COAL FLOW
BOTTOM MILLS E AND B



illustrates that this bias did persist over the entire long-term effort for high-load operation. fining the mill bias as the percent difference between the top and bottom mills one can estimate the long-term bias used for Phase 3B. Figure 6-13 illustrates the mill bias was on average approximately 30 percent, i.e., top mill had 30 percent higher coal flow than bottom mills.

Based upon data from Phase 3A, similar long-term evaluations were made. Figure 6-14 (a, b & c) illustrate that the mills were operated in a relatively uniform manner over the Phase 3A long-term period. Figure 6-15 shows that, for the most part, the Phase 3A bias was in the order of 5 percent or nearly uniform coal flow for each level of mills.

This evaluation of the long-term mill flow characteristics further supports the contention that the mill bias could be a contributing factor to the low emission levels experienced during the Phase 3B short- and long-term test efforts. This bias coupled with the change in fuel characteristics could explain the discrepancy between the apparent contribution of AOFA between Phases 1 and 2 and Phases 3A and 3B. It is therefore believed to be inappropriate to assume net the AOFA operation with LNBs resulted in a NOx reduction effectiveness in the order of 40 percent. Furthermore, it was shown in the Phase 3A Special LOI Tests that the burner tuning contributed only slight changes in the NOx levels.

Based upon the evaluation above, if the true AOFA affect were assumed to be 16.3 percent, then the NOx levels for the same coal and same bias as experienced in Phase 3A at high load would be 0.54 lb/MMBtu for the LNB plus AOFA configuration. This would mean that the Phase 3B NOx level with AOFA operation would be approximately 0.14 Ib/MM8tu above that actually experienced during the long-term test at full-load. At least half of this 0.14 lb/MMBtu difference could be explained by the mill bias used during the Phase 3B testing. Some portion of the remaining 0.07 Ib/MMStu could be explained by the differences in the burner settings between the Phase 3A and Phase 3B testing and could reasonably be expected to be in the order of 0.04 Ib/MMBtu based upon Phase 3A Special LOI test data. The remaining 0.03 Ib/MMBtu could be attributed to the differences in the coal FC/VM ratio between the two phases, however, the exact amount of this contribution is not known. Assuming that this allocation is correct, burner adjustments similar to those performed in the Phase 3B during Phase 3A

FIGURE 6-13 PHASE 3B LONG-TERM MILL BIAS

PERCENT DIFFERENCE BOTTOM TO TOP MILL FLOW

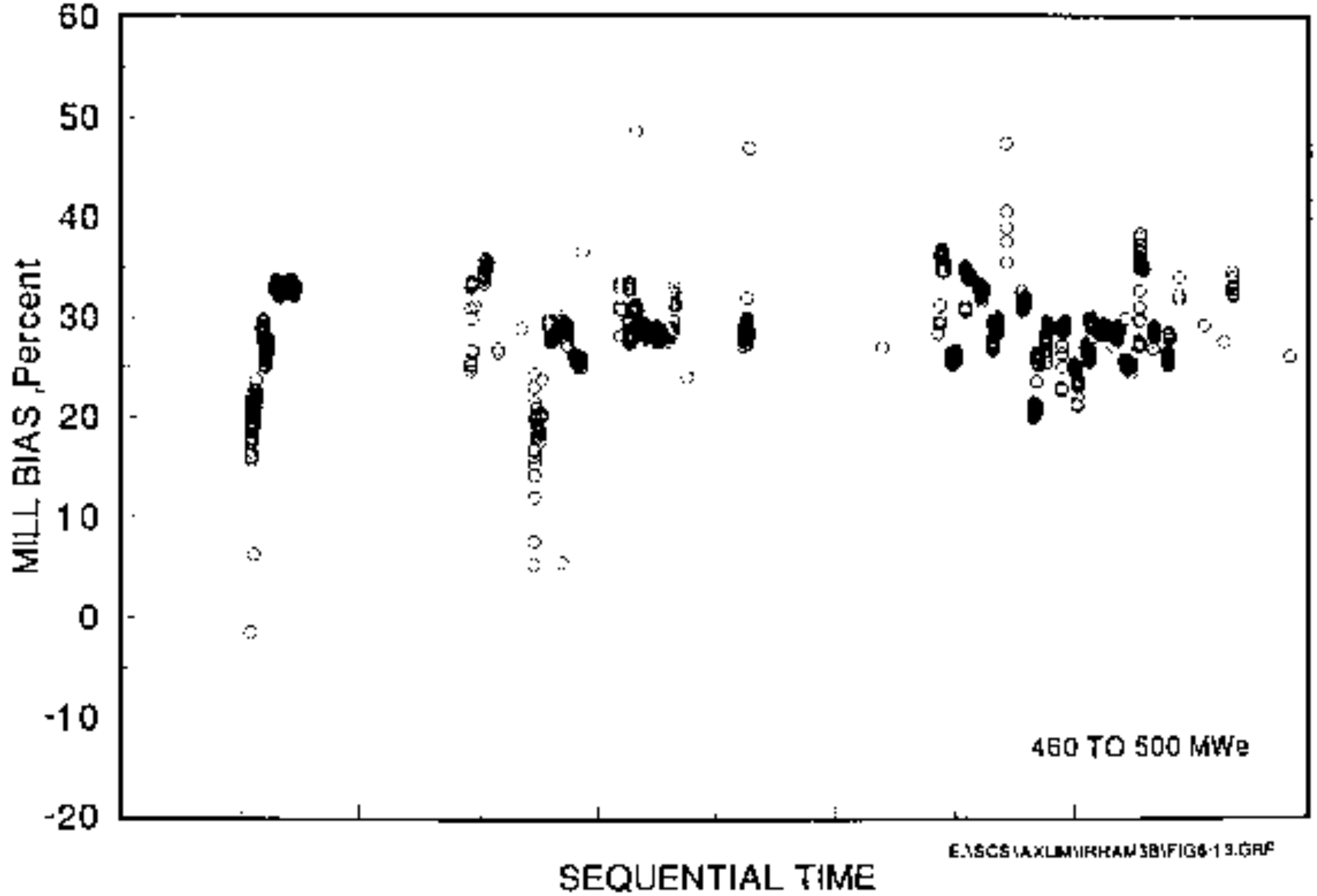


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FIGURE 6-14a PHASE 3A LONG - TERM MILL COAL FLOW
TOP MILLS C AND F

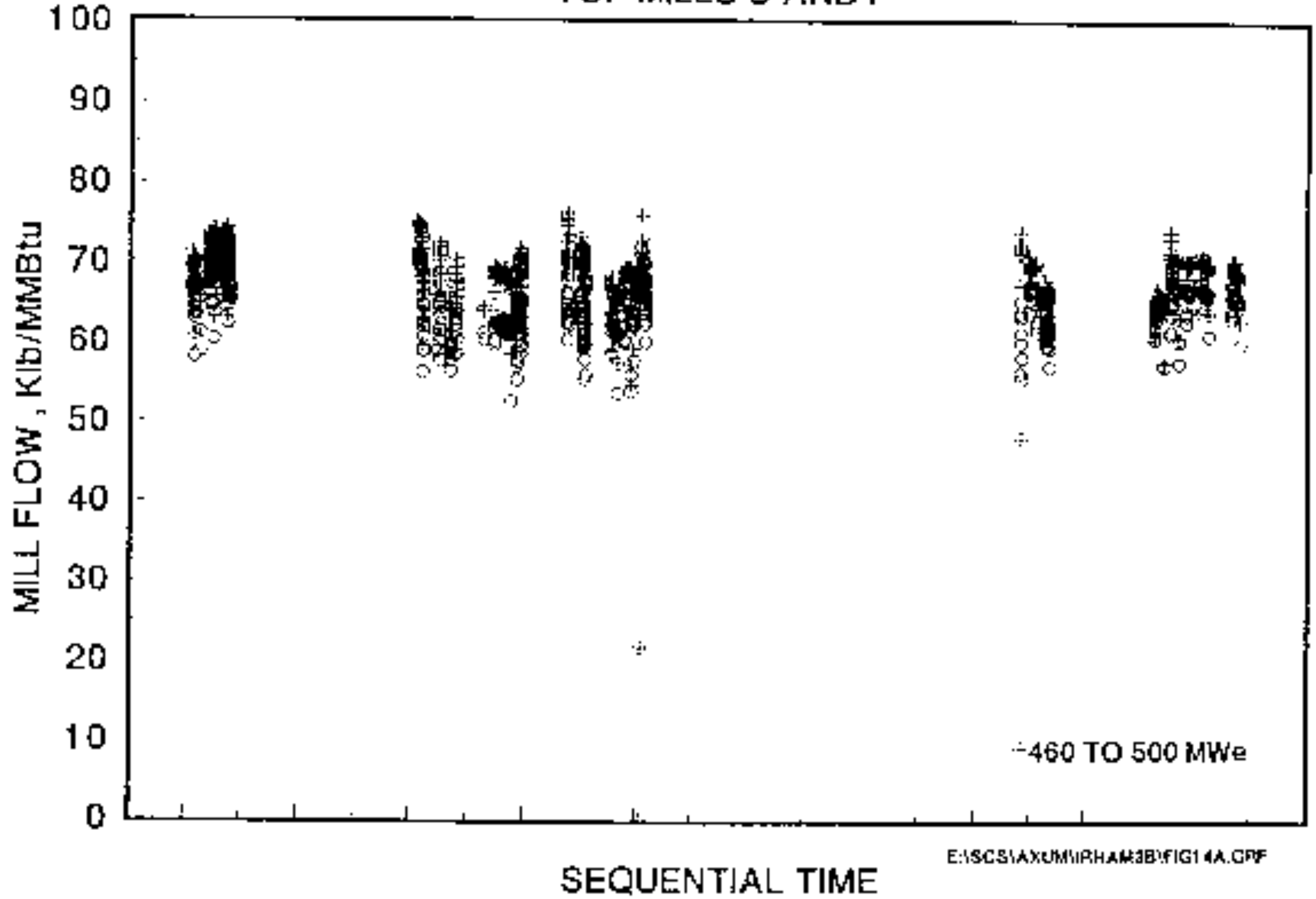


FIGURE 6-14b PHASE 3A LONG - TERM MILL COAL FLOW

CENTER MILLS D AND A

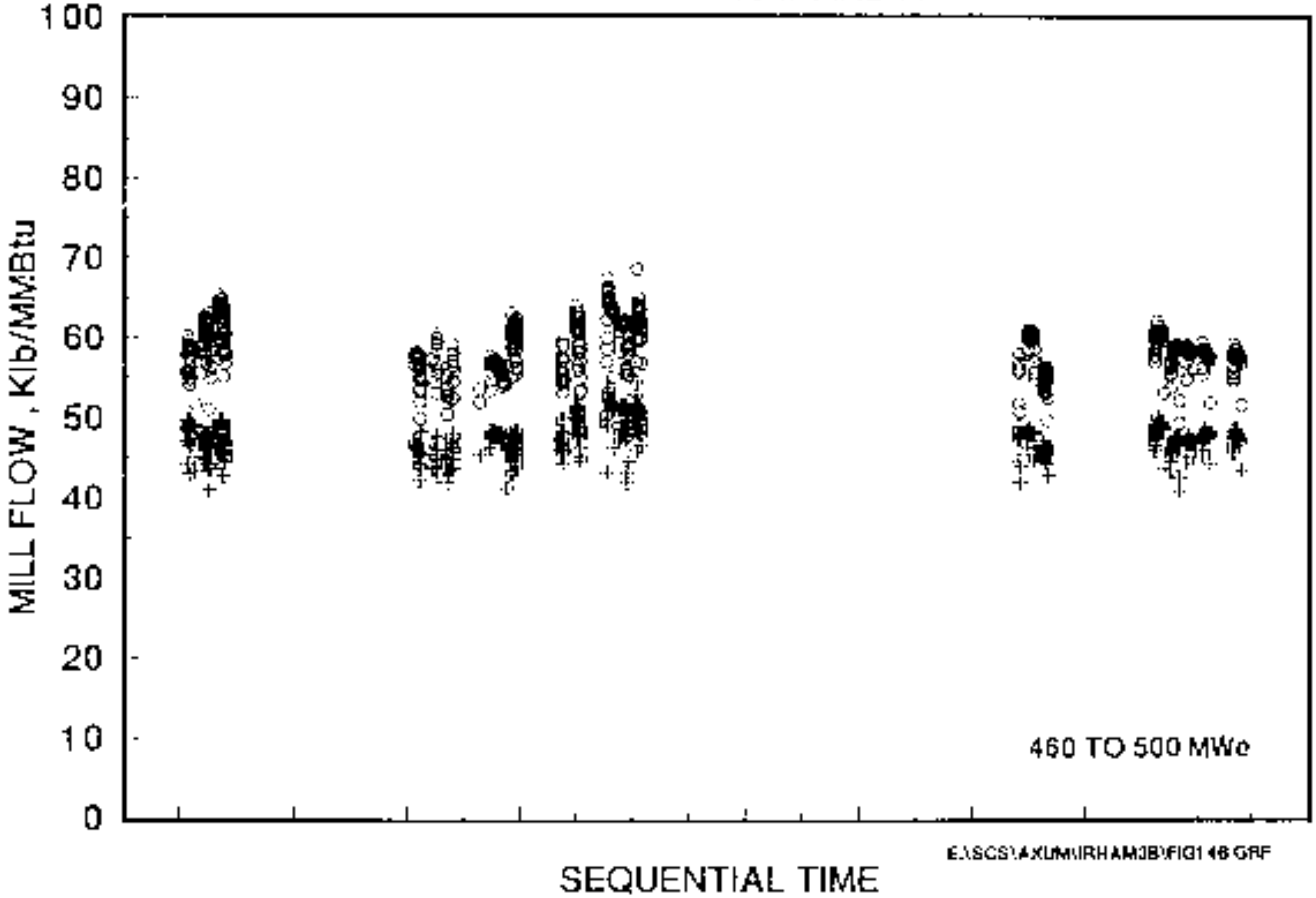
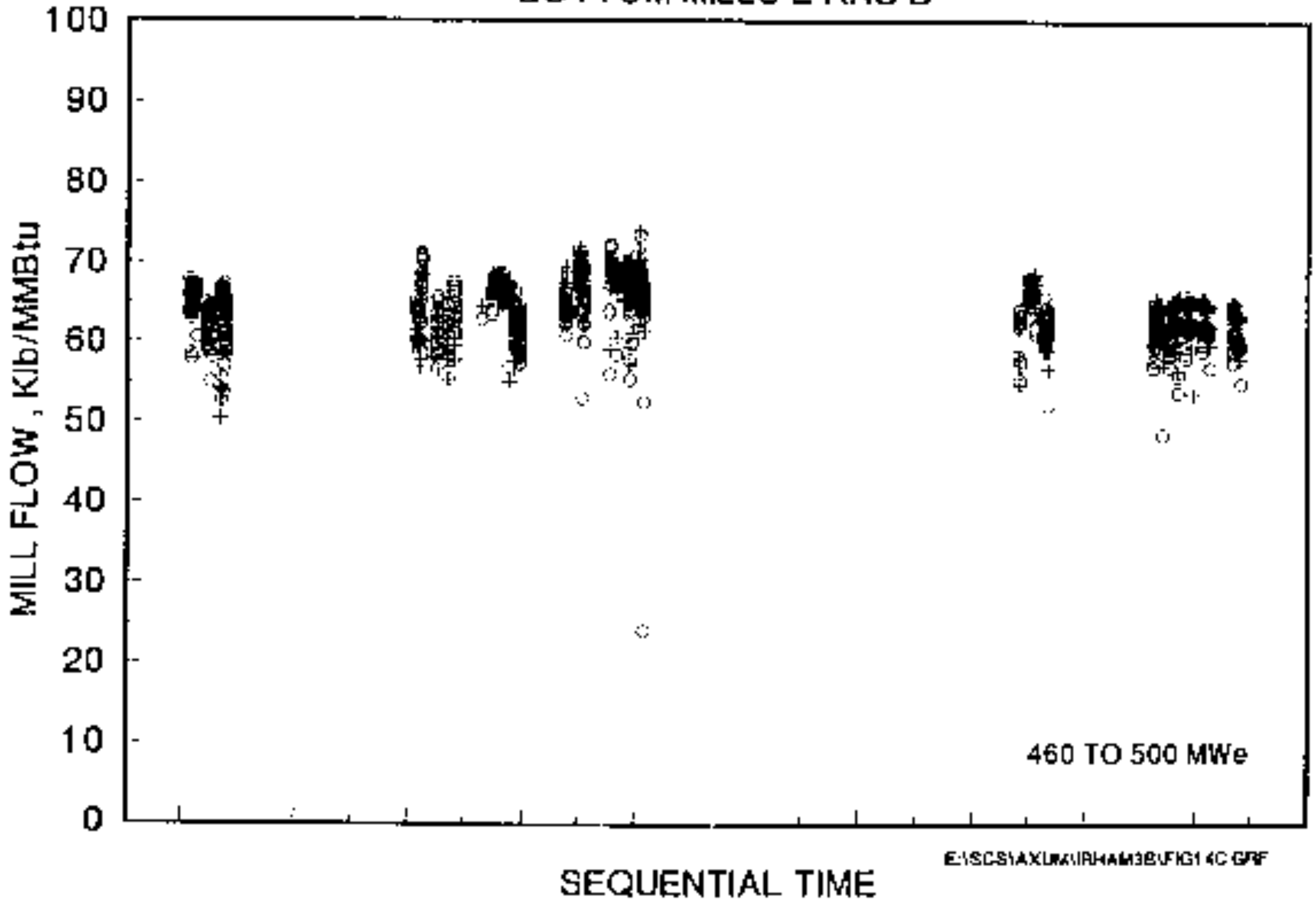


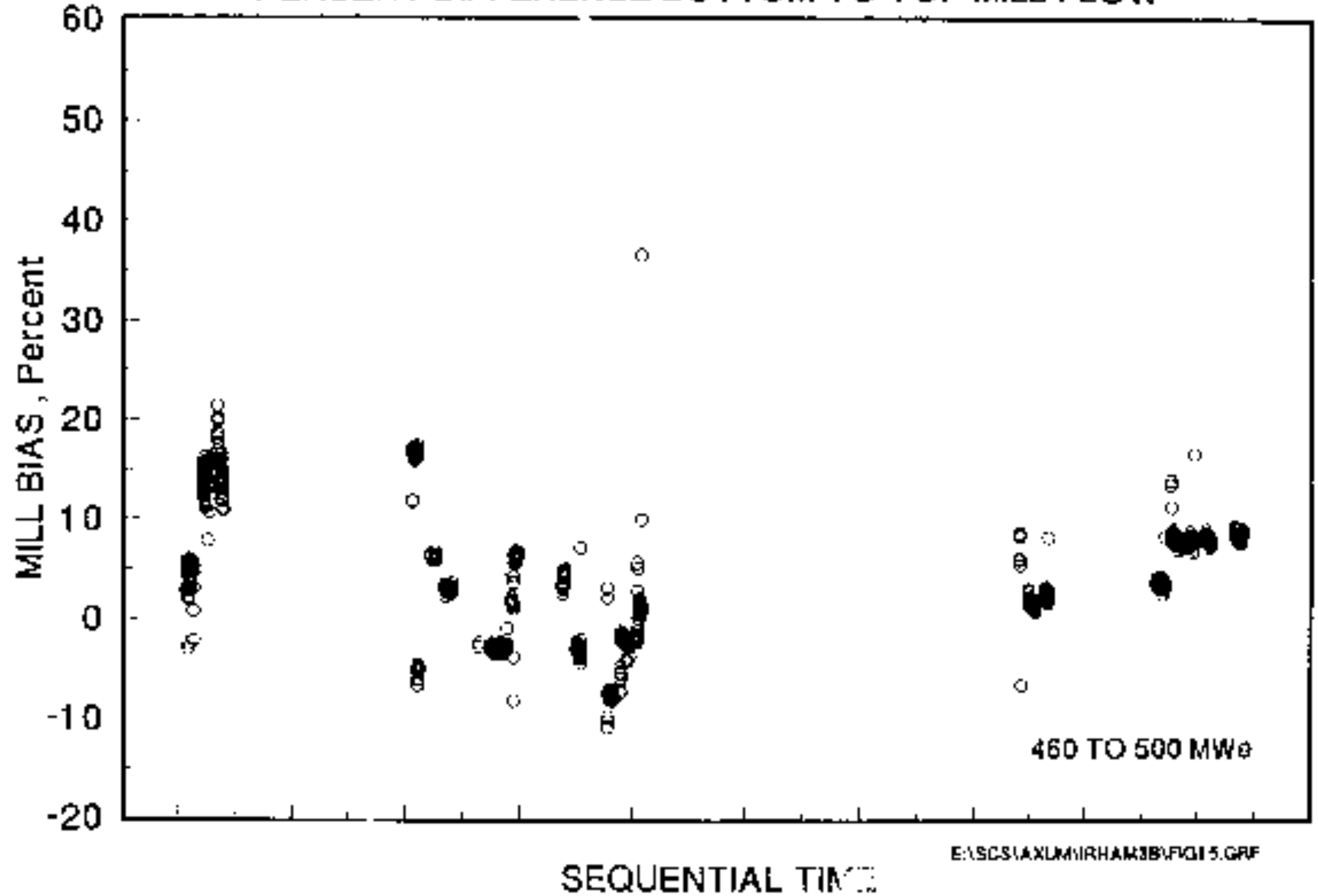
FIGURE 6-14c PHASE 3A LONG - TERM MILL COAL FLOW

BOTTOM MILLS E AND B



E:\SCS\AXUM\IRHAM3B\FIG14C.GRF

FIGURE 6-15 PHASE 3A LONG - TERM MILL BIAS
PERCENT DIFFERENCE BOTTOM TO TOP MILL FLOW



(LNB only) effort might have reduced the high-load NOx emissions to 0.50 lb/MMBtu. The application of AOFA in combination with LNB with the Phase 3A coal and with nominally no mill bias would have resulted in an adjusted Phase 3B full-load NOx level of 0.42 lb/MMBtu - very close to the measured level of 0.40 lb/MMBtu.

7.0 CONCLUSIONS

The primary objective of the Phase 3B test effort was to establish LNB plus AOFA retrofit NOx emission characteristics under short-term well controlled conditions and under long-term normal system load dispatch conditions. In addition' other important performance data related to the operation of the boiler in this retrofit configuration were documented for comparison to those measured during the Phase 1 baseline test effort. Protocols for data collection and instrumentation operation were established during Phase 1 (see Phase 1 Baseline Tests Report).

The following paragraphs provide brief discussions of the conclusions that can be drawn for the short-term and the long-term test results. Conclusions related to the comparison of the short- and long-term results are also presented. Brief discussions related to the comparison between Phase 1 and Phase 3B data are included as well as a discussion concerning the anomalies related to results from Phase 3A and 3B.

7.1 Short-Term Characterization Tests

During both the diagnostic and performance portions of this test effort, the coal supply remained relatively constant. The following paragraphs provide a brief description of the major conclusions for the Phase 3B short-term testing.

7.1.1 Diagnostic Test Conclusions

The conclusions for the diagnostic portion of the testing are based primarily upon testing performed at 300, 400 and 480 MWe. The major conclusions for the Diagnostic testing are:

1) NOx emissions were considerably less variable than for Phases 1 and 2 of the program. The variation during Phase 3B appeared to vary by as much as 0.08 to 0.9 lb/10^6MMBtu. This was approximately equal to that experienced during Phase 3A.

2) For one operating condition (mill pattern and load) NOx trends could be determined if O_2 excursions were performed on the same day and in a monotonic fashion. All of the trends for all loads and mill patterns exhibited increasing NOx with increasing O_2. The sensitivity with excess oxygen level at each load varied from 0.076 to 0.029

3) NOx emissions over the load range from 180 to 480 MWe increase from approximately 031 to 0.43 lb/10^6MMBtu.

4) Short-term test to modulate the AQFA dampers indicated that AOFA operation at the 55 percent open damper position resulted in approximately 16 percent NOx reduction.

7.1.2 Performance Test Conclusions

The performance tests documented the unit characteristics at nominal loads of 300, 400 and 480 MWe. Over the 10 to 12 hour period of the individual performance tests, the unit operated under extremely stable normal operating conditions. The major conclusions for the performance tests are:

1) The NOx scatter evidenced during the diagnostic tests was also present during the tests for nearly identical operating conditions (mill pattern and load).

2) Primary air to coal flow ranged from 2.13 at 480 MWe to 2.63 at 400 MWe. At 300 MWe the A/F ratio was between these two at 2.46.

3) Mill coal particle fineness was above that for any of the other phases due to the installation of four new mills out of six. The coal fineness was determined to be 73 percent average through a 200 mesh screen at 480 MWe. Pipe-to-pipe coal flow were + 30 to -34 percent from the mean at the full-load point. The primary air to

coal, ratio in the mills was ± 8 percent from the mean at full-load This is considerably unproved over that experienced during previous performance test phases.

4) An inadvertent bias in the coal flows to the upper and lower sets of mills existed during the Phase 3B effort. As much as 30 difference in coal flows existed between the bottom and top mills with the top mills canny the highest coal flow. This bias potentially favorably impacted the NOx emissions which may have resulted in reduced levels of NOx emissions during this phase of the program.

5) LOI ranged from 5.7 to 8.0 percent over the load range from 300 MWe to 480 MWe, respectively. The LOI measurements indicated that LOI remained approximately equal to that measured during Phase 3A The LOI was, however, significantly increased over that for the original baseline configuration.

7.2 Long-Term Characterization Tests

Long-term testing took place from mid-May 1993 through mid August 1993. During this period the CEM was operated 24 hours per day except during periods of repair and calibration. From time-to-time, the instrumentation experienced operational difficulties which resulted in lost data capture. These periods were minimal and did not affect the quality of the remainder of the data. Sufficient data was collected to perform meaningful statistical analyses for both engineering and regulatory purposes.

The following paragraphs provide the major conclusions that can be drawn from the long-term test results.

1) Data show that the unit experienced only minor periods of time where the average daily load was below the 300 MWe range (60 percent load)

2) Daily average NOx emission level for the long-term test period ranged from approximately 032 to 0.58 Ib/10^6MMBtu.

3) The mean load characteristics showed that NOx exhibited a constant NOx relationship as load was increased from 480 to 200 MWe. Below 200 MWe the NOx increased as load was decreased. The 95 percent confidence intervals for NOx emissions over the load range was on the order of $\pm$ 0.15 lb/MBtu about the mean.

4) Based upon 30-day rolling averages, the data showed that the average load was 314 MWe over the period of long-term testing. The 30-day rolling average NOx remained relatively constant after the first 20 rolling average days ranging from approximately 0.42 lb/10^6MMBtu.

5) Statistical analyses indicated that the Phase 3B data were autocorrelated with a correlation coefficient of $r = 0.69$. The data are more highly autocorrelated than the data collected in Phase 1 or Phase 2 and about equal to that experienced during Phase 3A. The time dependent NOx emission characteristics resulting in a 30-day rolling average achievable emission limit of 0.51 lb/10^6MMBtu.

6) Subsequent to the Phase 1 testing the Clean Air Act Amendments of 1990 passed requiring annual average emission rate limits. The time dependent NOx emission characteristics ($r = 0.73$) resulted in an annual average achievable emission limit of 0.42 lb/10^6MMBtu.

73 Comparison of Phase 1 and Phase 3B Emission Data

While the Phase 1 and Phase 3B efforts were not performed with the same load scenario, some general conclusions can be made with regard to the effectiveness of the LNB retrofit. The following briefly summarizes these conclusions.

1) Aside from LOI and NOx, all other solid and gaseous emission characteristics remained near the levels of those for the baseline configuration.

2) LOI emissions increased over the baseline configuration. At the 480 MWe load point, the LOI increased by as much as approximately 50 percent to a level of 8.0 percent.

3) NOx emissions decreased by approximately 67 percent from the baseline configuration at 480 MWe. The emission reduction increased as the load decreased to the 300 MWe load point where the reduction was a maximum at approximately 54 percent. The effectiveness decreased to approximately 43 percent at the low load point of 180 MWe.

7.4 Comparison of Phase 3A and Phase 3B Emission Data

The apparent effect on NOx from operation of the AOFA ports with LNBs was in the order of 40 percent further reduction. This apparent affect did not take into account that a number of changes existed between conditions of Phase 3A and 3B. During the Phase 313 performance testing it was discovered that a number of factors may have affected the NOx emissions that resulted from the Phase 3B LNB plus AOFA evaluation These were related to the coal properties, burner settings and the mill bias described above. The following briefly presents the major conclusions due to these differences between Phase 3A and 3B.

1) Coal properties were relatively constant, with the exception that the coal sulfur was higher than during Phase 3A and the fixed carbon to volatile matter ratio was lower. The latter parameter could cause the NOx to be lower for the Phase 3B coal than the Phase 3A coal.

2) Mill coal flow patterns were in the direction of the optimum for low NOx operation during Phase 3B. Phase 3A operated with nominally no mill bias.

3) Burner settings may have been more favorable for low NOx operation during Phase 3B than during Phase 3A

The net result of these factors potentially is that if both phases had been operated in the same manner, the AOFA contribution to the total NOx reduction for Phase 3B would have been in the order of 16 to 18 percent. Therefore for the Phase 3B configuration operating with no mill bias, no burner adjustments and the Phase 3A FC/VM ratio, the Phase 3B long-term NOx emissions at 480 MWe would have been more in the order of 0.45 rather than the 0.40 lb/MMBtu measured during the Phase 3B long-term test effort. Burner adjustments could potentially have further reduced the level to 0.42 lb/MMBtu

It is undeniable that the retrofit achieved the low levels of 0.40 lb/MMBtu, however, this level may have been achieved under the most favorable conditions. Furthermore, the operation of the unit intentionally in a biased mill configuration might not be acceptable for other applications due to mill throughput limitations.

These results are presented as the first indications of the impacts of the burner operating variables on LOI and NOx on the Hammond Unit 4. Additional analyses will be performed subsequently and included in the Final Report of the Hammond CCTII project.